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AN RF LINK ANALYSIS OF MSBLS DURING ALT

AVIONICS SYSTEM ENGINEERING

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1.0 SUMMARY

An analysis of the microwave scanning beam landing system (MSBLS) ground station to Orbiter radio frequency (RF) link was made to determine if the expected signal levels will be compatible with Orbiter receiver capabilities. Of primary interest was whether or not loss of data will occur due to interference caused by the Orbiter 101 nose boom which provides additional air data during the approach and landing test (ALT).

The results of this analysis indicate that a small amount of data loss may occur due to the close proximity of the MSBLS antennas and the nose boom.

2.0 INTRODUCTION

One of the RF navigational aids which will be utilized during ALT is the MSBLS. The Orbiter MSBLS antenna locations along with the nose boom used during ALT is shown in Figure 1. The MSBLS provides range, azimuth, and elevation data relative to two ground transmitter locations adjacent to the runway. The azimuth and distance measuring equipment (DME) transmitters will be located just a few feet from each other at the far end of the runway. The elevation station will be just beyond the nominal touchdown point and both sites are 300 feet to the right of the runway center line (Reference A). This is shown in Figure 2.

Each MSBLS update cycle consists of a sequence of events beginning with a DME solicit signal transmitted by the Orbiter. The DME ground station then replies yielding range information and initiates scans by the azimuth and elevation stations. As this scanning takes place the spacing between pulse pairs is varied proportional to the ground station antenna angle. These spacings and the range information are processed onboard the Orbiter to determine the position relative to the runway. This cycle is repeated 5 times each second.

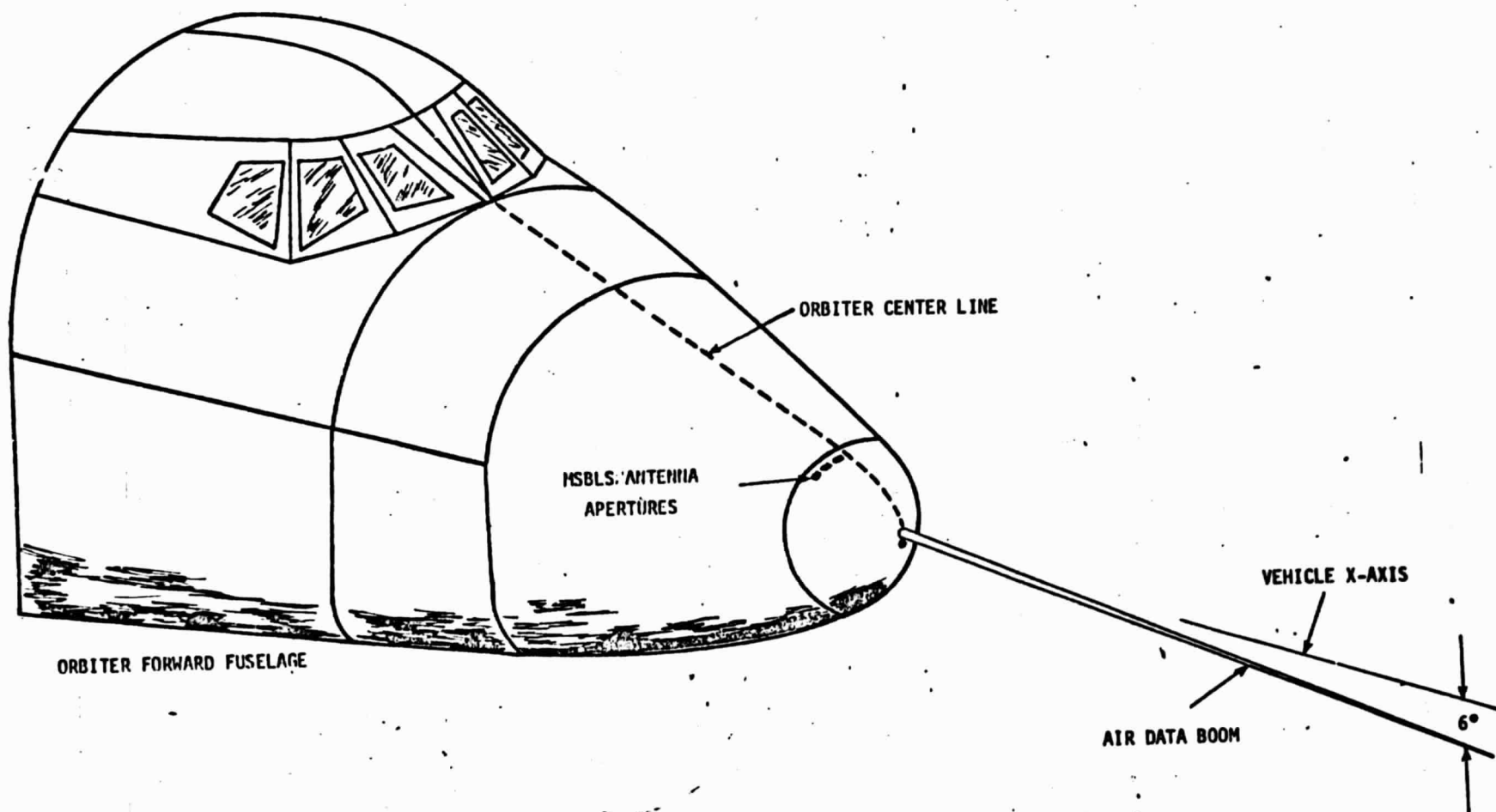


FIGURE 1
PROXIMITY OF MSBLS ANTENNAS
AND AIR DATA BOOM

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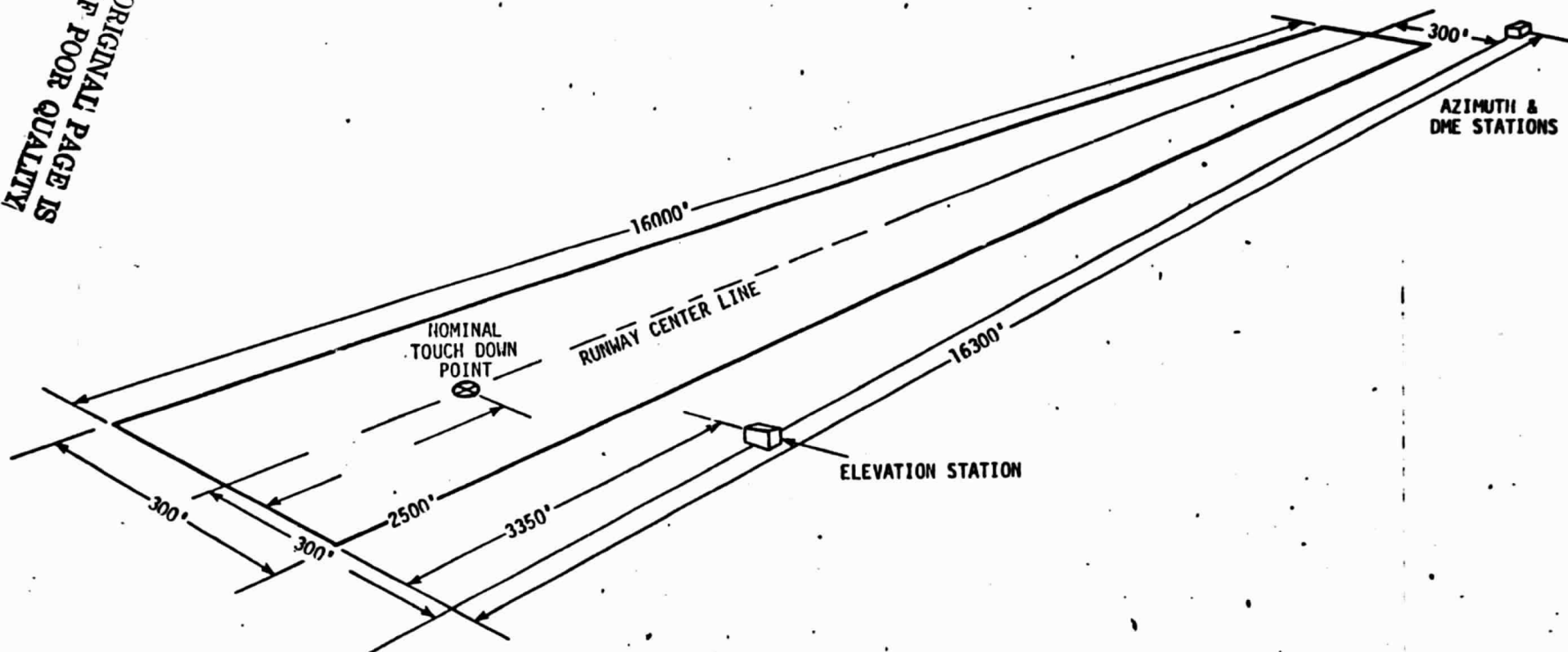


FIGURE 2
MSBLs GROUND STATION
STATION LOCATIONS

The MSBLS onboard receiver may lose lock for either of 2 reasons:

- o The signal may become weaker than the receiver threshold sensitivities. These are -74 dBm for the elevation and azimuth signals and -77 dBm for DME received power level (Reference B).
- o The receiver may lose lock if the signal level fluctuates too fast for the automatic gain control (AGC) loop to track. This will be discussed in greater detail later.

The basic analysis performed in Reference (C) has been repeated to include the effects of the following considerations.

- o A change in the baselined ground station locations
- o A new Orbiter guidance model
- o A change in the nominal touchdown point
- o Ground station antenna patterns were defined
- o More detailed information on the AGC Loop

3.0 DISCUSSION

The power received by the Orbiter MSBLS receiver at any particular time can be computed by using the Friis transmission formula:

$$P_r(\text{dBm}) = P_t(\text{dBm}) + G_t(\text{dBi}) + G_r(\text{dBi}) + 20 \log \left[\frac{\lambda}{4 \pi R} \right] (\text{dB})$$

Where:

$P_r(\text{dBm})$ = received power (decibels above a milliwatt)

$P_t(\text{dBm})$ = radiated power

$G_t(\text{dBi})$ = transmitter antenna gain (decibels above isotropic)

$G_r(\text{dBi})$ = receiving antenna gain (includes circuit losses)

λ = wavelength (meters)

R = slant range (meters)

The last term represents the free space path loss (FSPL) in decibels.

The polarization loss due to rolling is assumed to be 0 dB in this analysis.

3.1 Derivation of Antenna Look Angles

The Space Shuttle Functional Simulator (SSFS) was utilized to determine the look angles for the various antennas. The landing was simulated for the ALT configuration from an altitude of 12,500 feet to touchdown.

Computer runs for 4 different wind conditions were made. These include:

(1) no winds, (2) headwinds with gusts, (3) tailwinds with gusts, and (4) crosswinds with gusts. The headwinds and tailwinds cases resulted in very similar look angle rates, so the tailwinds will be ignored for this analysis. Gusts of 50 knots were encountered during the wind runs. Although these winds may be considered unreasonable for ALT, it was apparent from the analysis that the winds make the received power histories only slightly more erratic.

Figure 3 illustrates the look angle convention used in this report. The look angle histories of the orbiter antenna for cases 1, 2, and 4 above are plotted in Figures 4, 5, and 6. These angles may be then transferred onto the MSBLS onboard antenna radiation distribution printout (RDP) to determine the gain at that angle.

The look angles for the ground station antennas were derived from simple trajectory information supplied by the SSFS and the ground station locations. This data was also utilized to plot the FSPL curves in Figure 7.

3.2 Antenna Pattern Descriptions

The onboard antenna RDP (Figure 8) illustrates the interference caused by the air data boom when compared to the RDP without the noseboom present (Figure 9). The dB numbers on these RDP's are negative and a printout of "0" represents a effective power gain of 5 dBi. A printout of "1" represents a power gain of 4 dBi, etc. When the final RDP's are made with the simulated TPS and nose boom

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θ - PITCH LOOK ANGLE
 ψ - YAW LOOK ANGLE
(ANGLE ROTATION SEQUENCE IS PITCH-YAW)

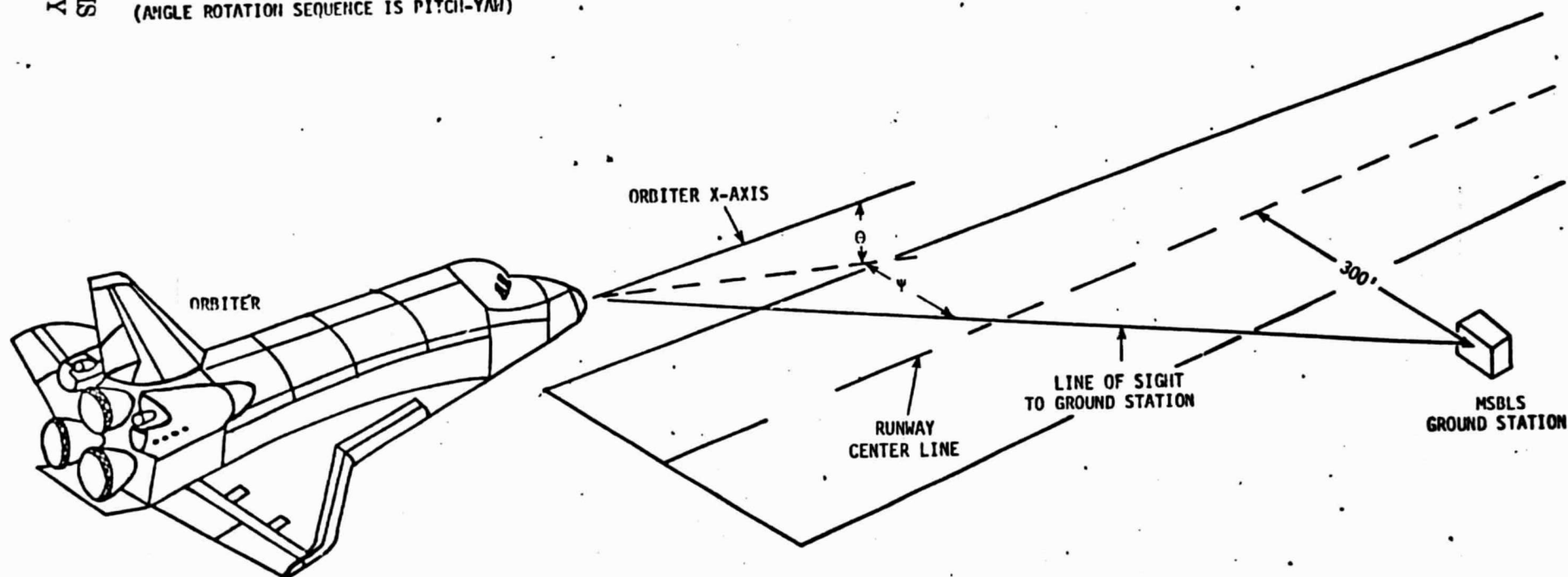


FIGURE 3
ORBITER TO MSBLS GROUND STATION
LOOK ANGLE GEOMETRY

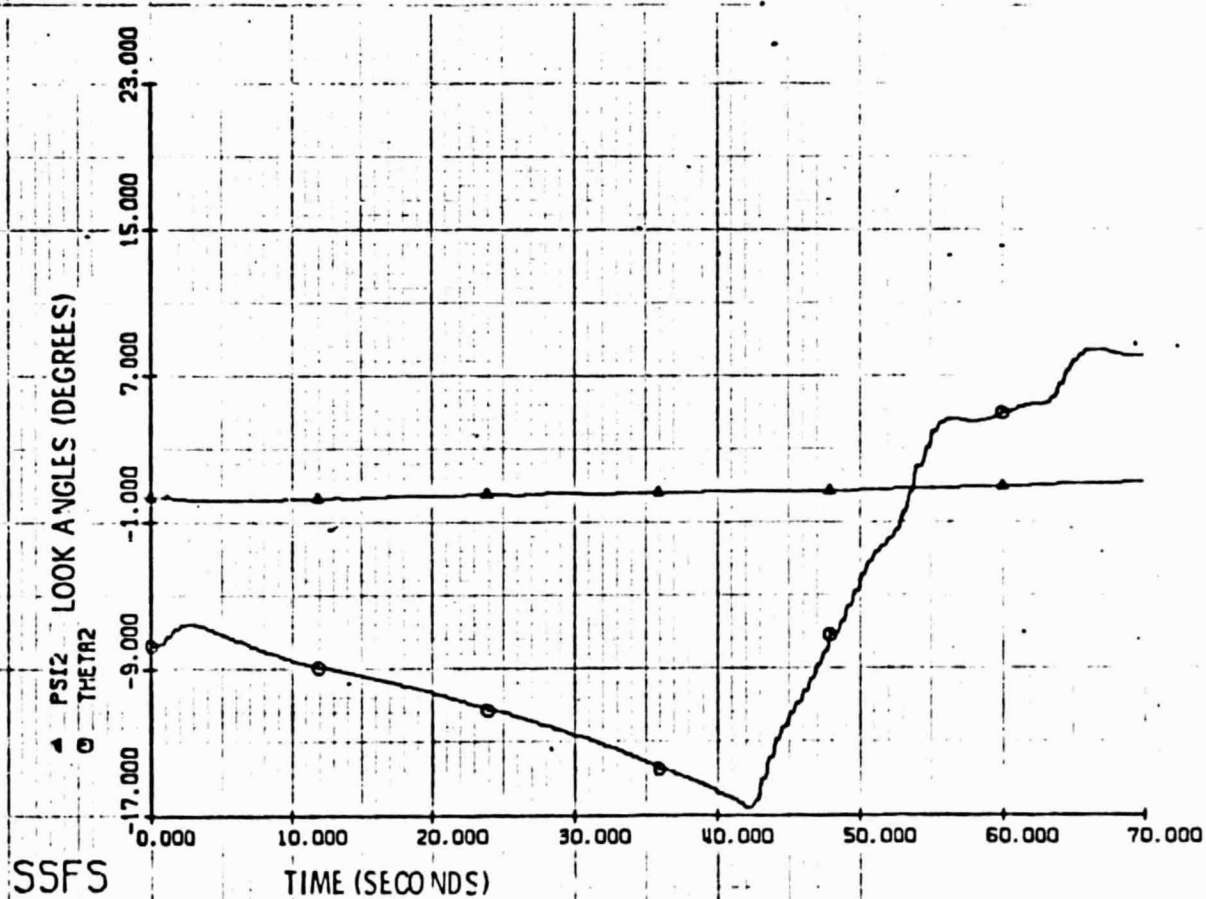
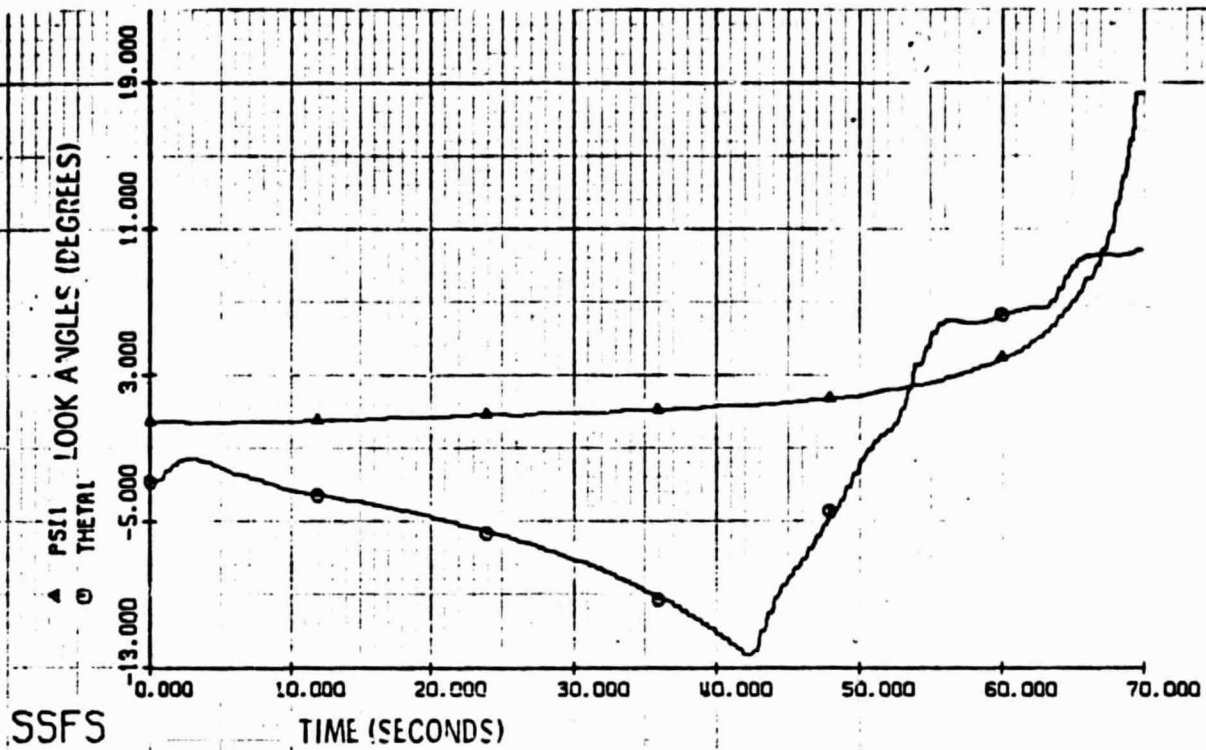
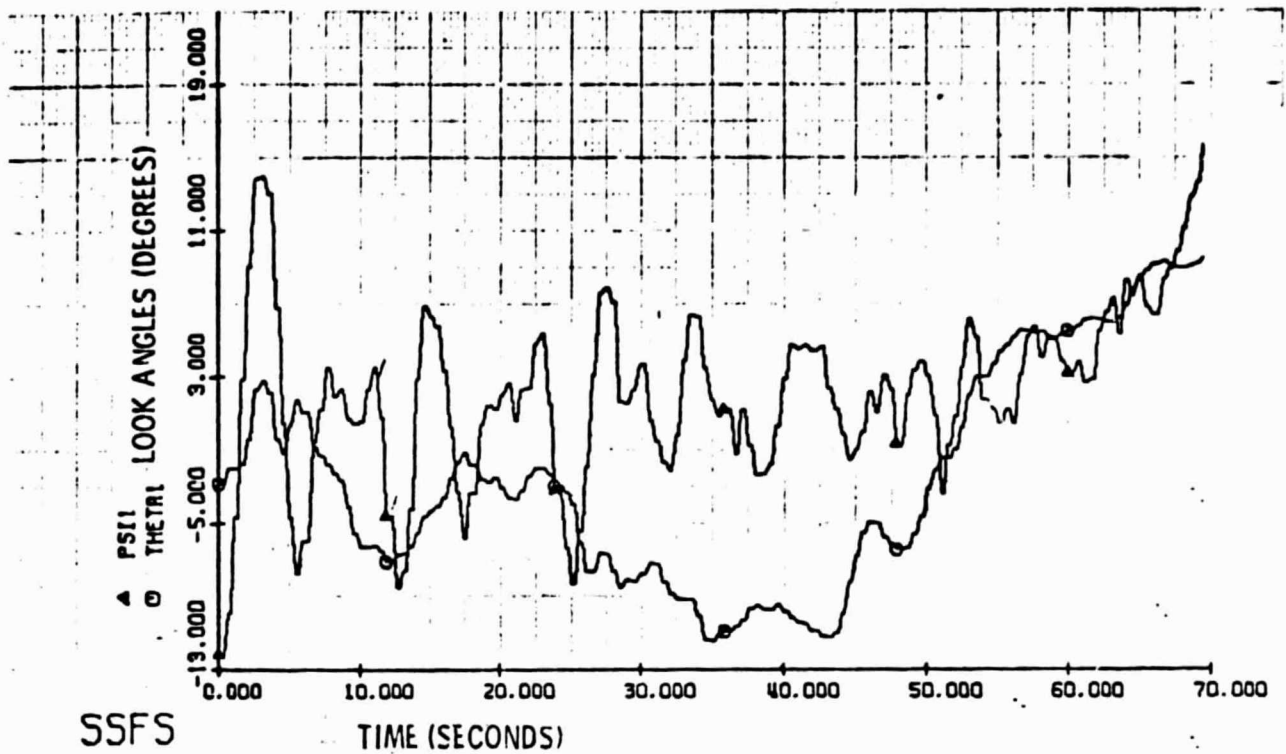
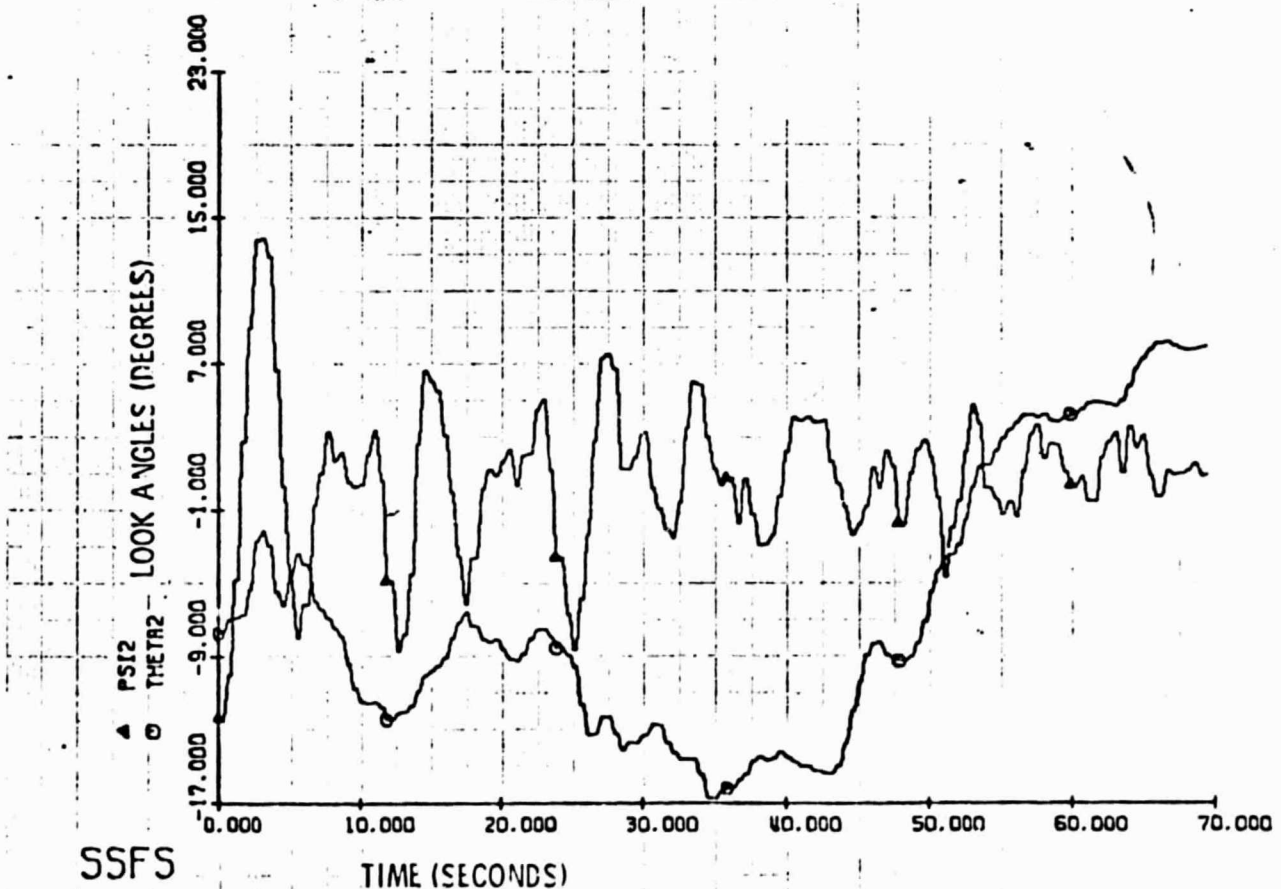


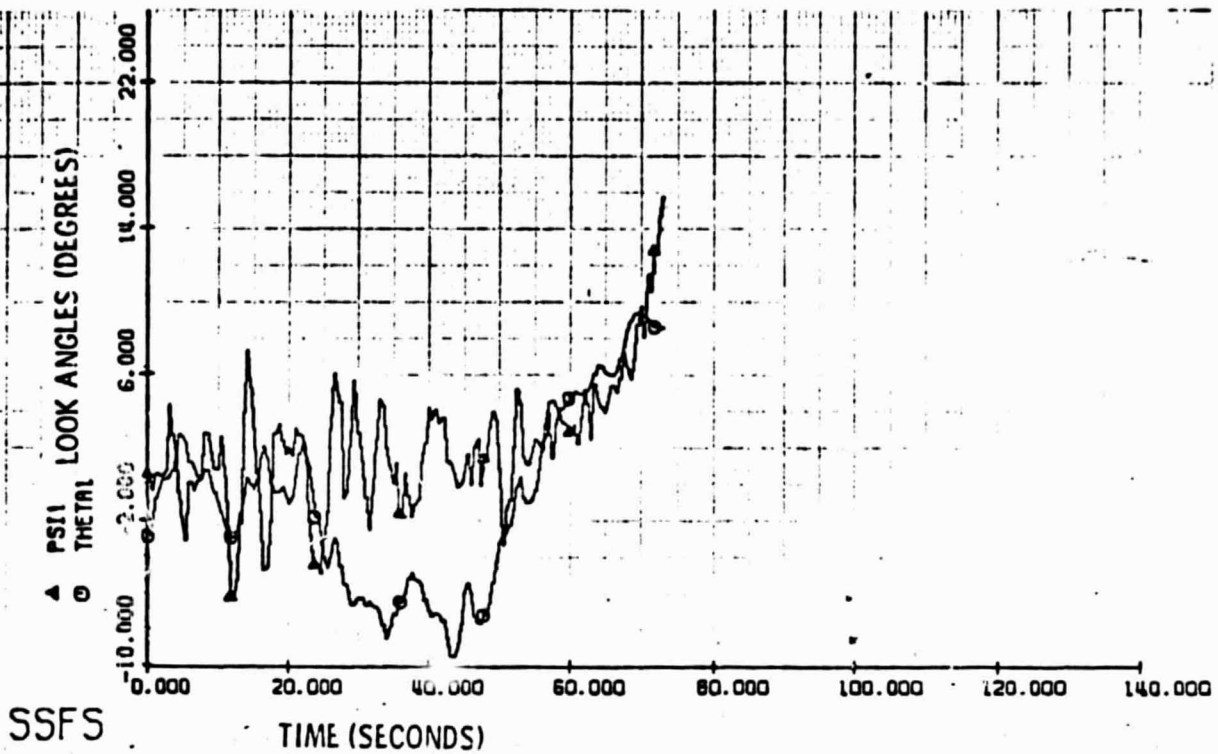
FIGURE 4



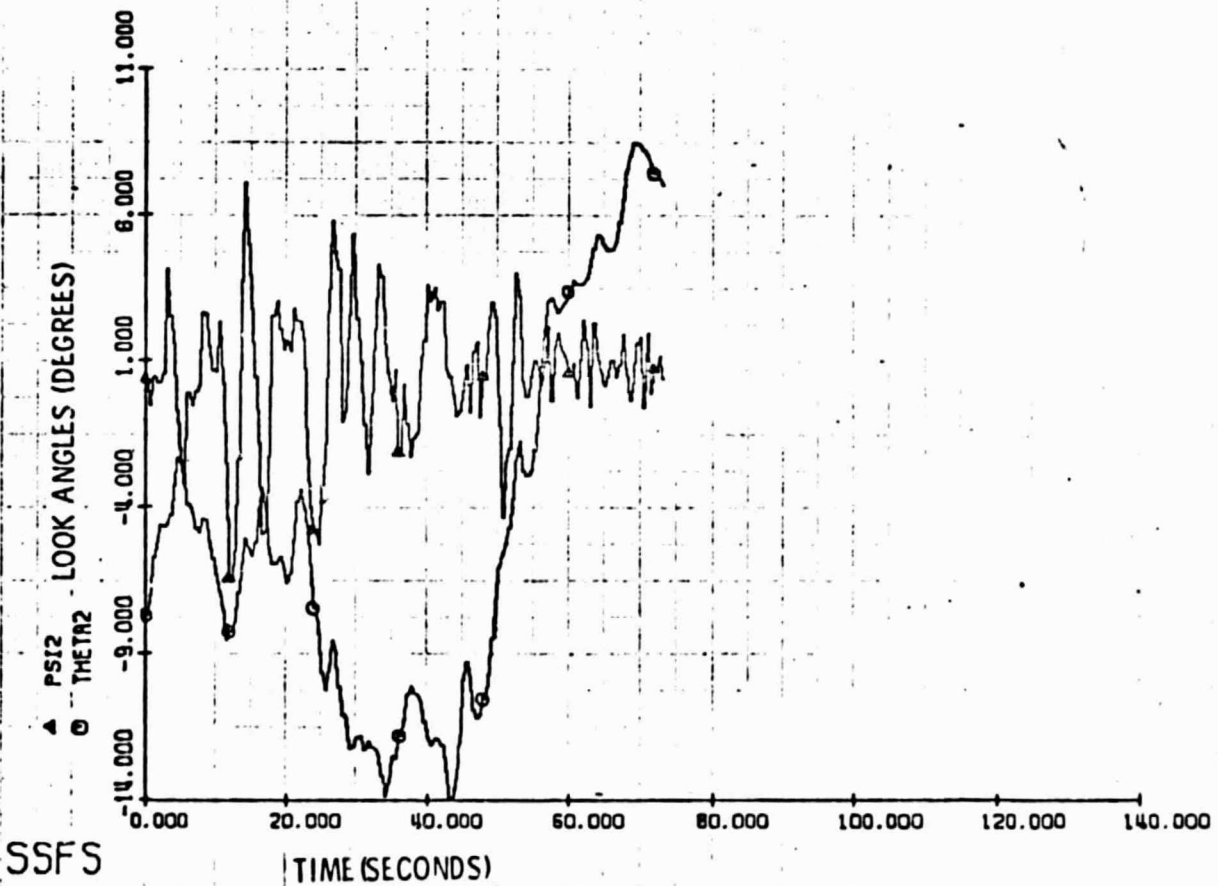
BOOM-C FIGURE 5A ANTENNA LOOK ANGLES TO ELEVATION STATION, WITH CROSSWINDS & GUSTS



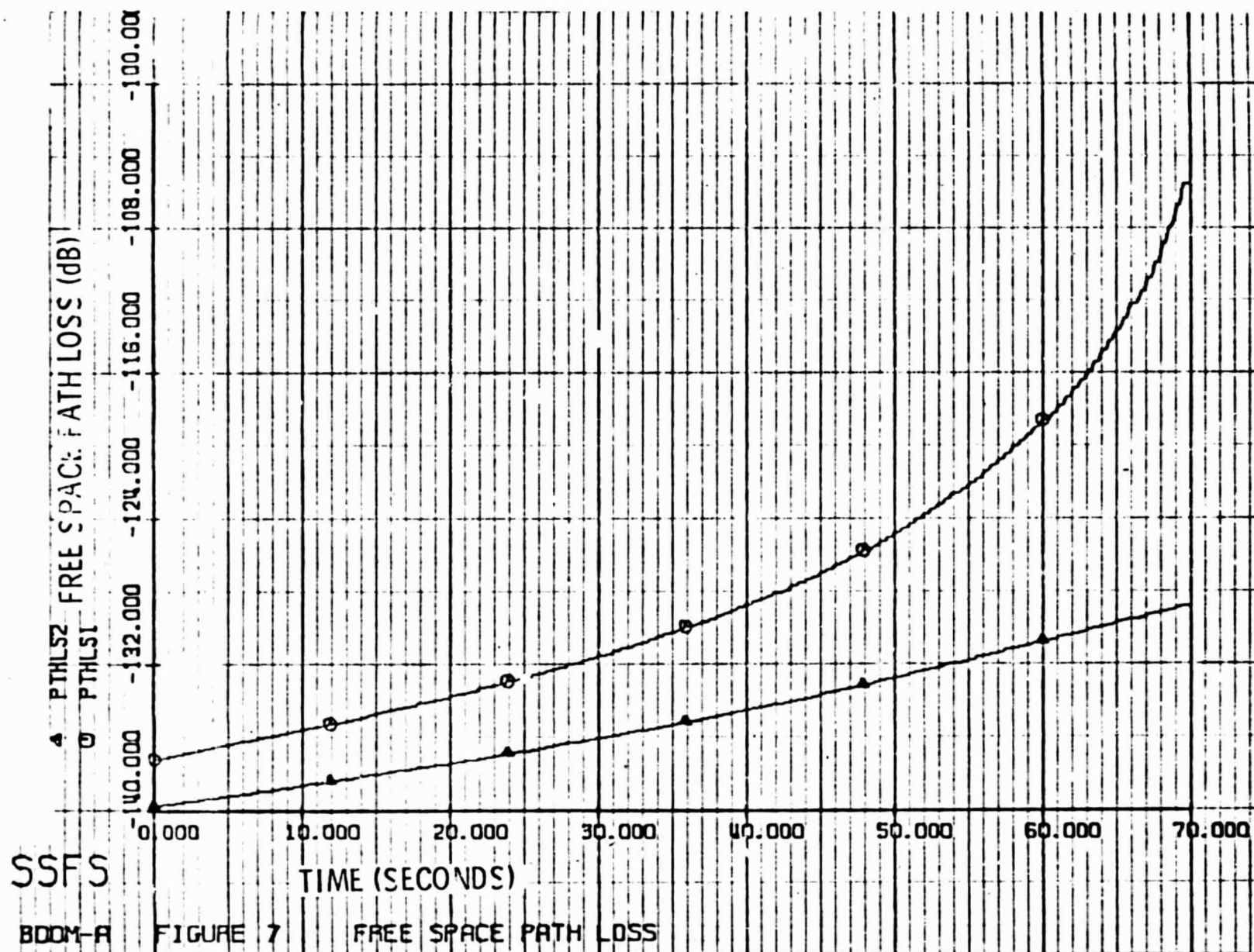
BOOM-C FIGURE 5B ANTENNA LOOK ANGLES TO AZIMUTH/OME STATION WITH CROSSWINDS & GUSTS



BOOM-B FIGURE 6A ANTENNA LOOK ANGLES TO ELEVATION STATION WITH HEADWINDS & GUSTS



BOOM-B FIGURE 6B ANTENNA LOOK ANGLES TO AZIMUTH/DME STATION WITH HEADWINDS & GUSTS



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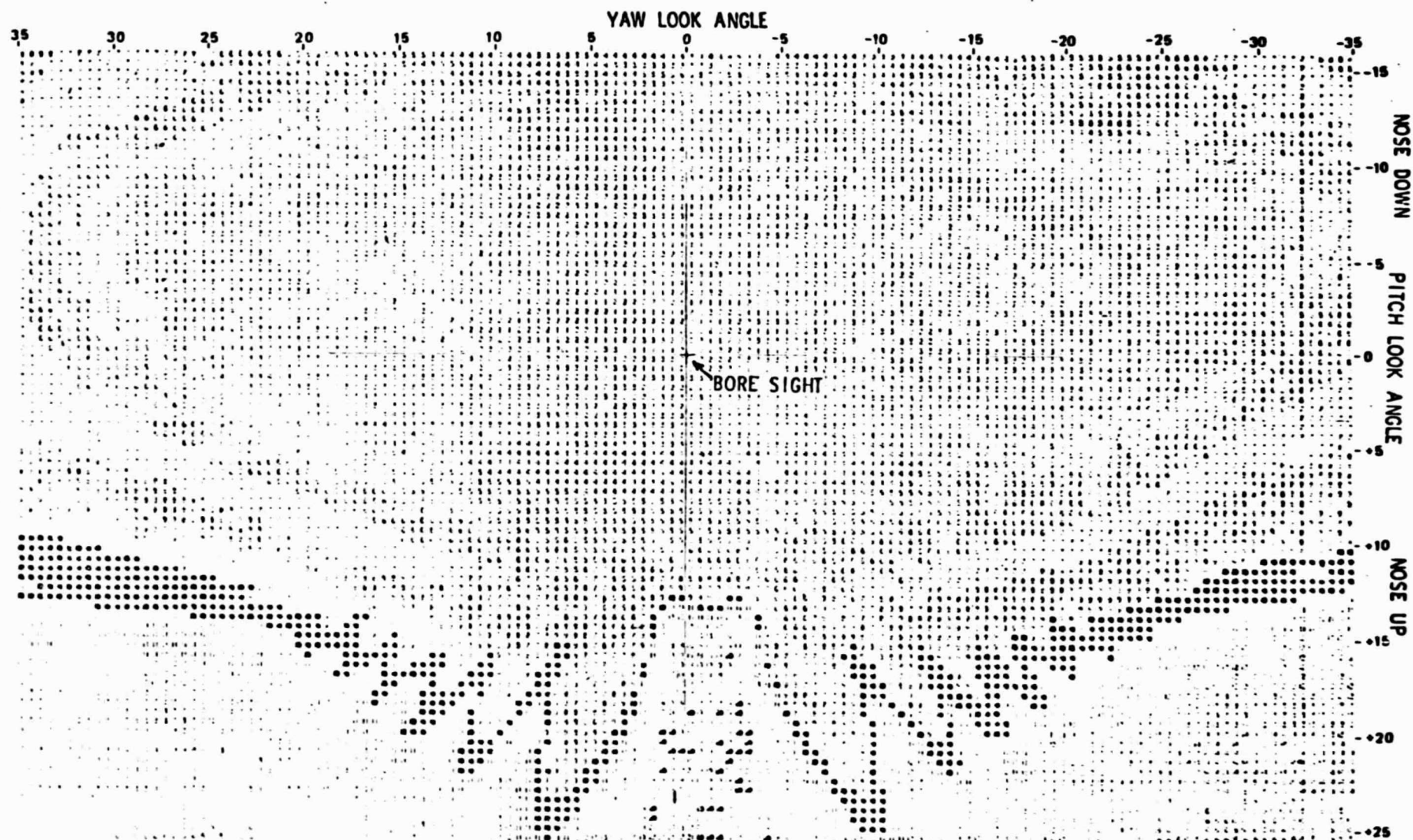


FIGURE 8 ONBOARD MSBLS ANTENNA RDP
WITH NOSE BOOM PRESENT

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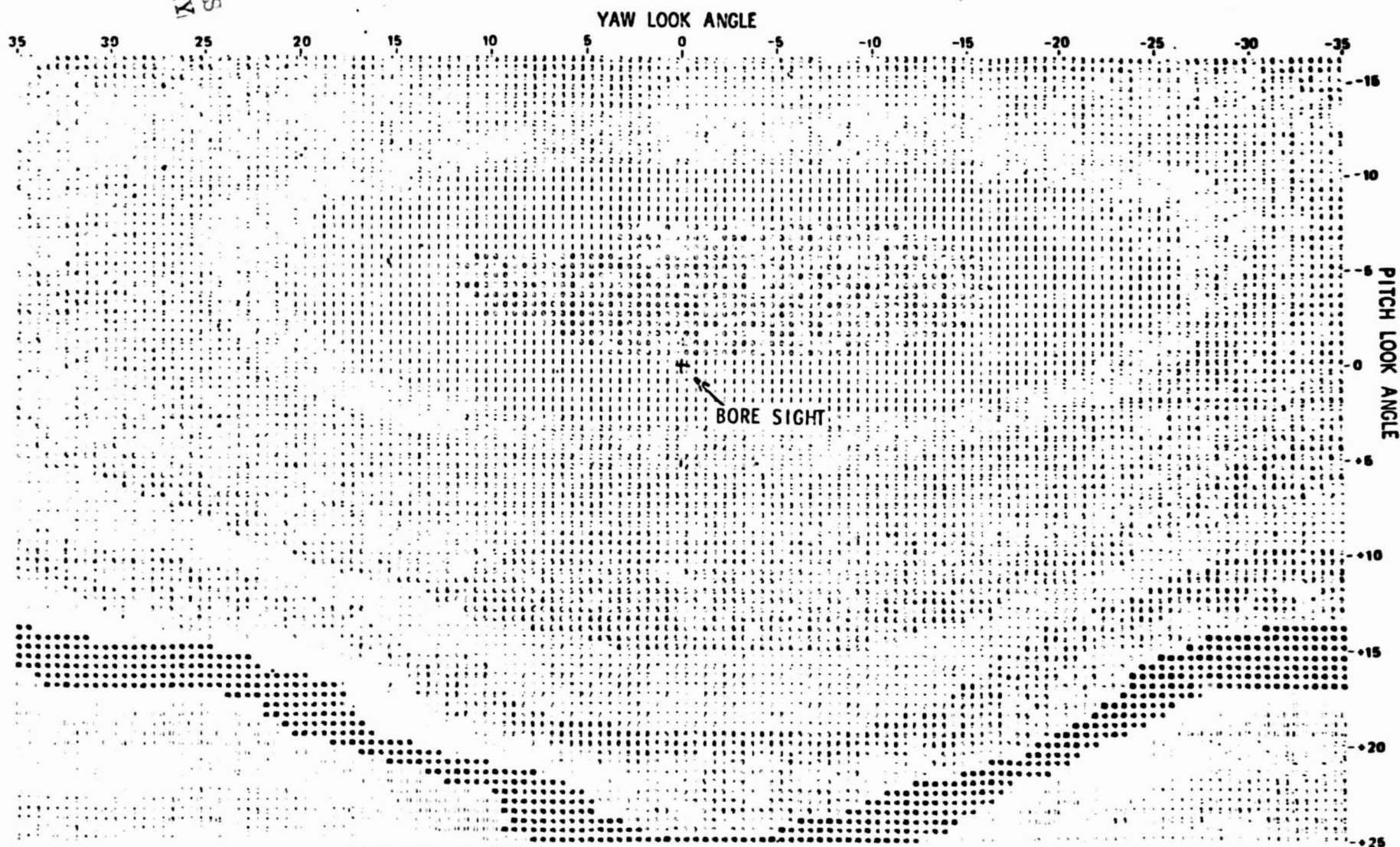


FIGURE 9 ONBOARD MSBLS ANTENNA RDP
WITHOUT NOSE BOOM PRESENT

present, the maximum power gain will most likely be in the 5 to 10 dBi range so the conservative value of 5 will be used for G_p .

The RDP with the nose boom (no thermal protection system (TPS) tiles present) illustrates 2 types of interference (Figure 8). In the lower central portion there exists a region of high attenuation due to nose boom shadowing. In the rest of the RDP, interference is present due to reflected radiation off the boom adding in or out of phase at the antenna depending on the look angle to the ground transmitter. In the upper portion of the RDP (looking above the nose boom) the angular frequency of the interference pattern is about 1 cycle per degree. This is shown on the right hand side of Figure 10 which is a pitch only "cut" from the middle of Figure 8. It is this region which produces the most difficulty for the AGC loop, as discussed later.

The ground station antenna patterns must now be analyzed to determine the transmitted power to various points along the ALT trajectory. The total radiated power of each ground station is 2.2 KW or 63.4 dBm (Reference D). The following summary table lists the maximum gain, initial and final pitch and yaw look angles and the corresponding gains.

TABLE 1. GROUND STATION LOOK ANGLES AND GAINS

GROUND STATION	ELEVATION	AZIMUTH	DME
MAXIMUM GAIN (dBi)	27	32	20
INITIAL PITCH LOOK ANGLE (deg)	-	13.5	13.5
INITIAL YAW LOOK ANGLE (deg)	0	-	0
INITIAL POWER GAIN (dBi)	27	32	19
FINAL PITCH LOOK ANGLE (deg)	-	0	0
FINAL YAW LOOK ANGLE (deg)	17	-	0
FINAL POWER GAIN (dBi)	25	25	13

These antenna patterns are shown in Figures 11 through 16. Since the MSBLS is vertically polarized the E and H plane patterns may be considered vertical and horizontal cuts respectively.

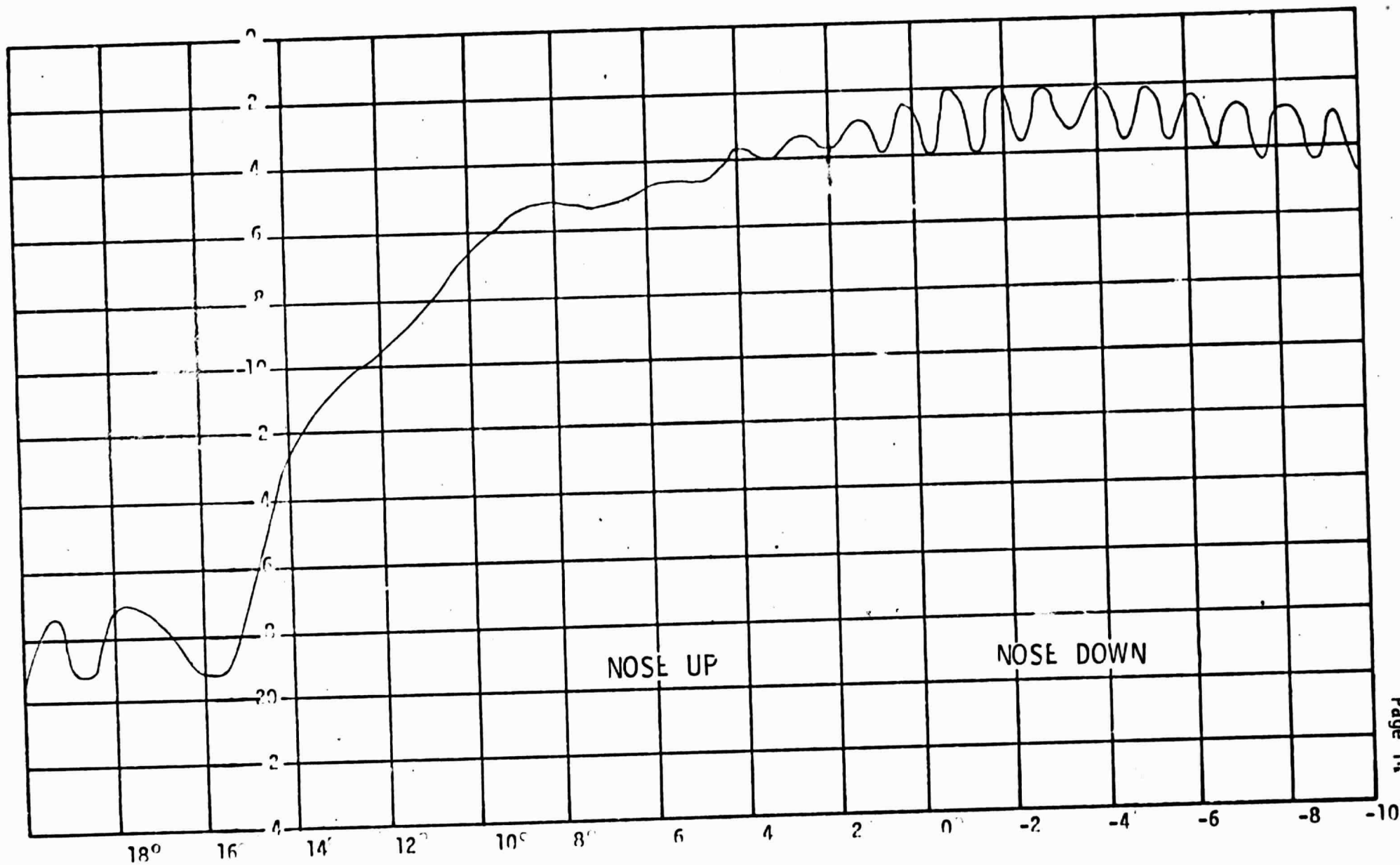


FIGURE 10
ONBOARD MSBLS ANTENNA PATTERN

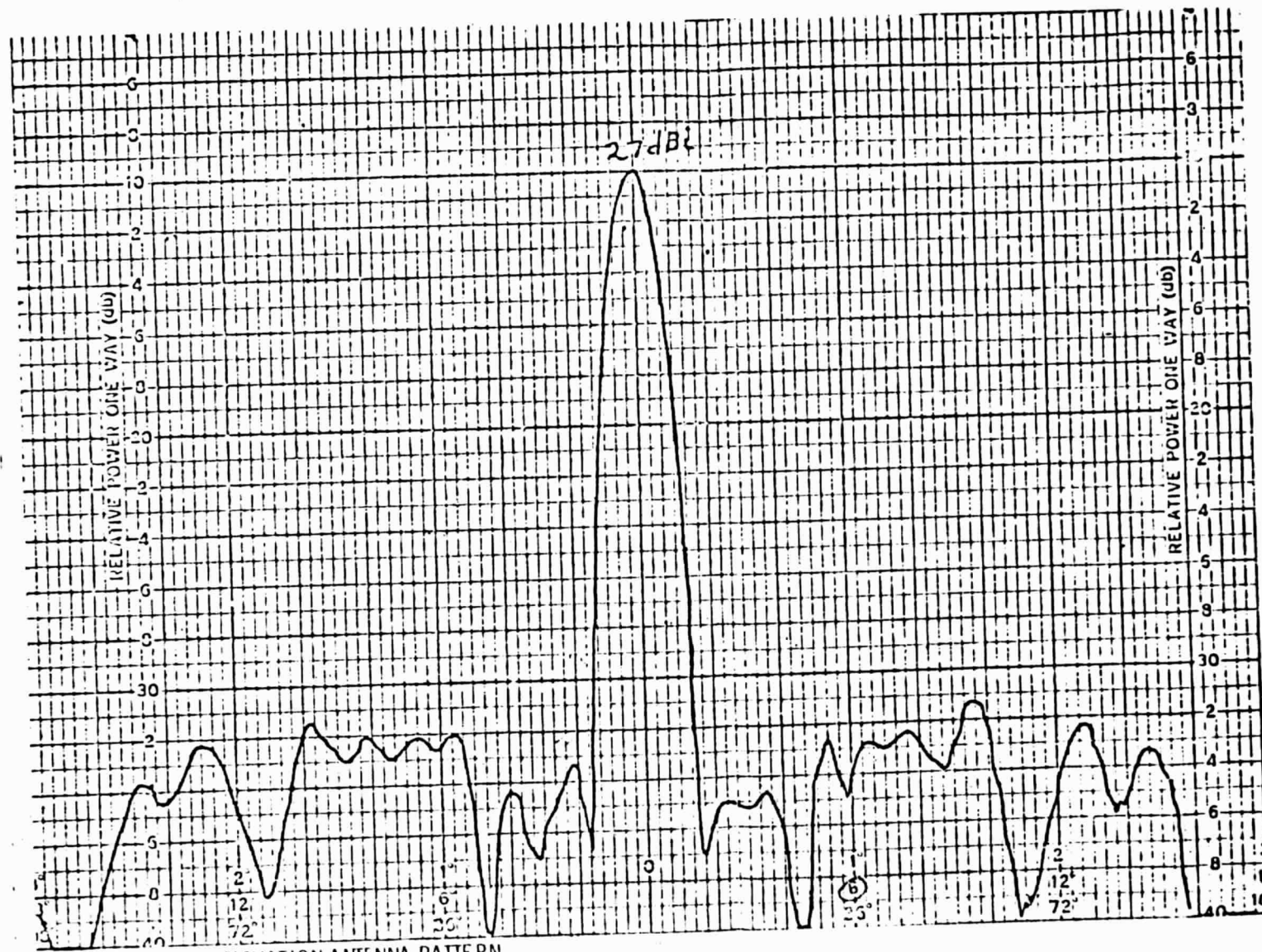


FIGURE II
ELEVATION ANTENNA PATTERN
(E PLANE)

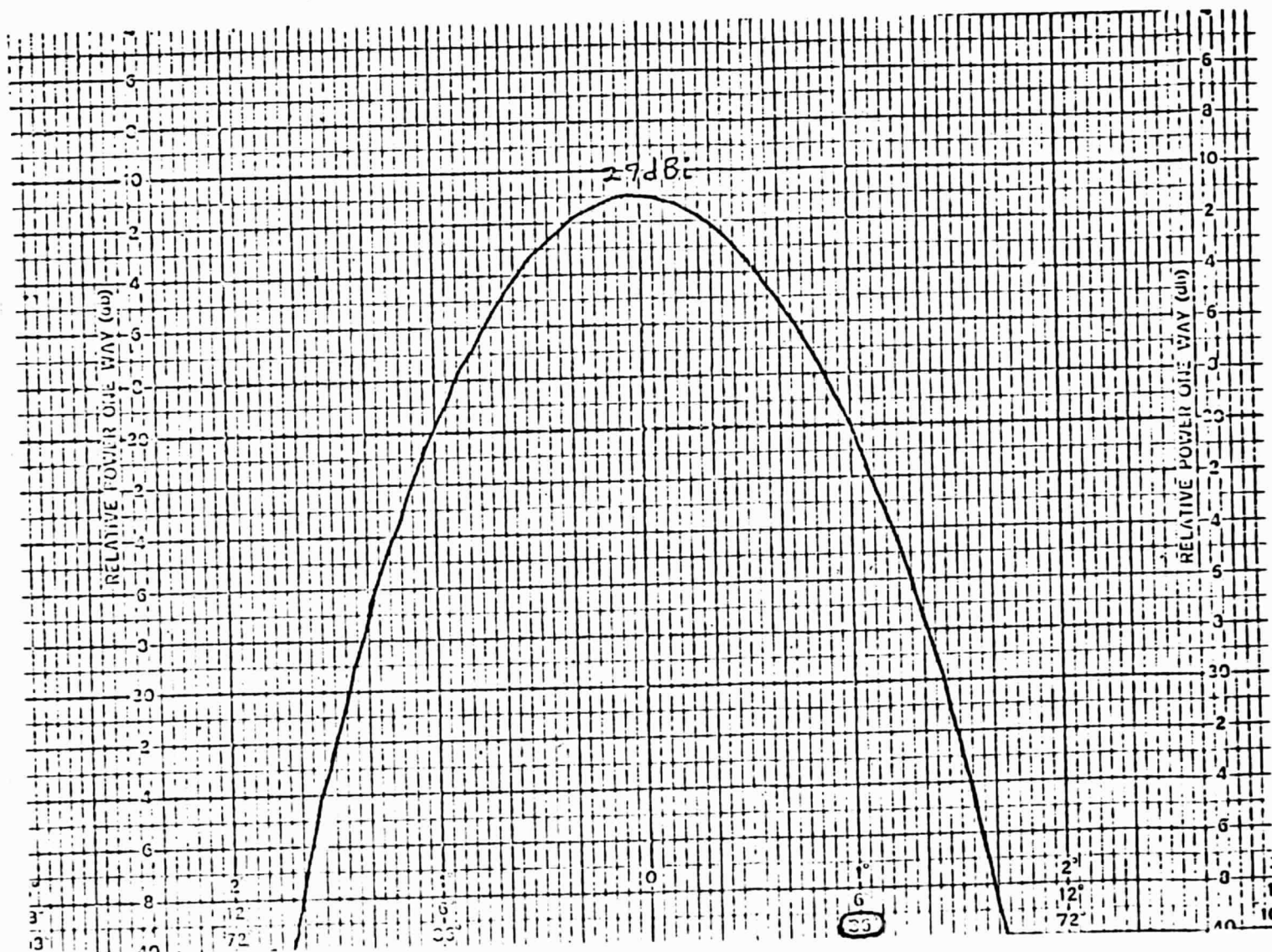


FIGURE 12 ELEVATION ANTENNA PATTERN
(H PLANE)

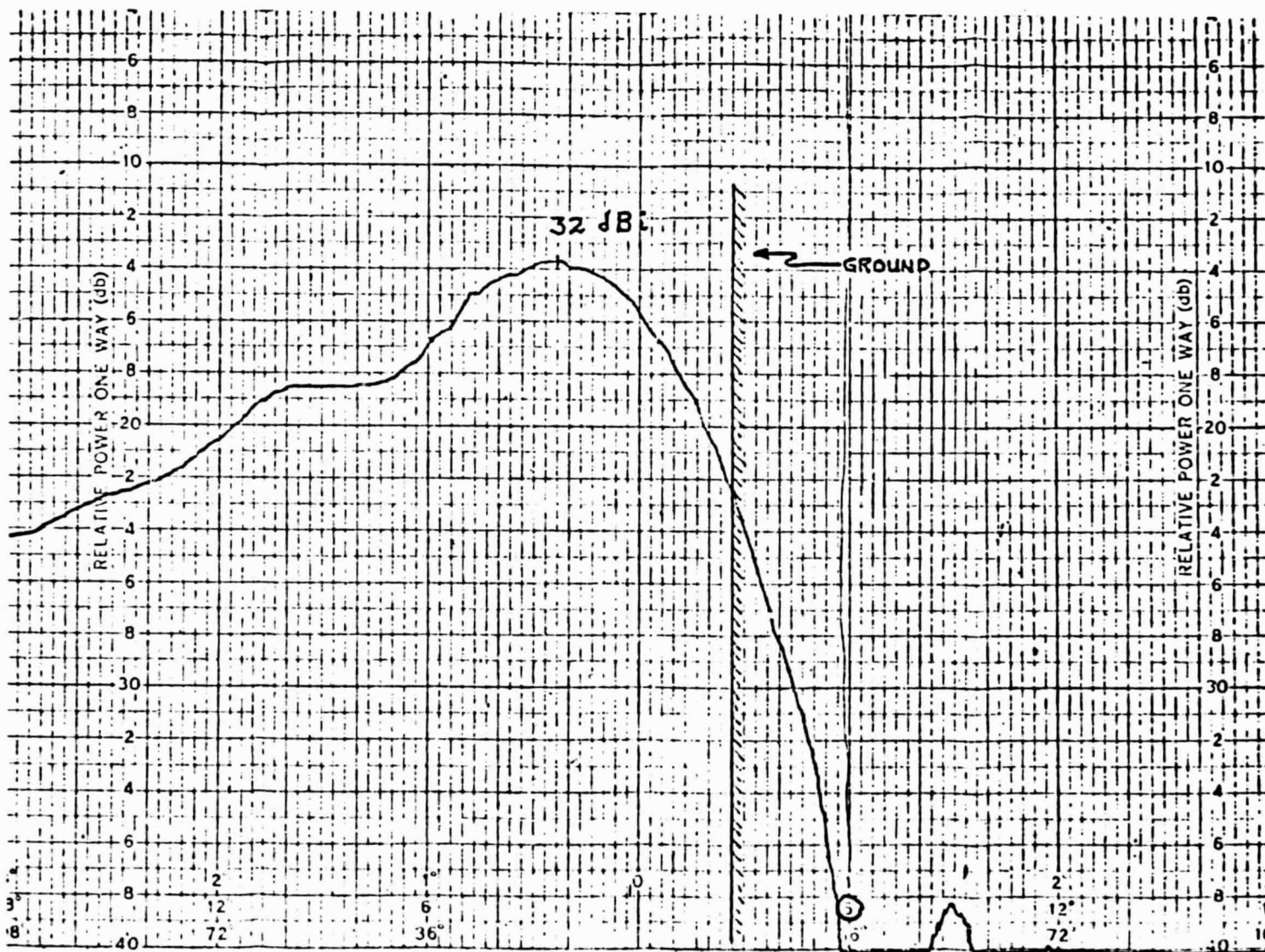


FIGURE 13 AZIMUTH ANTENNA PATTERN
(E PLANE)

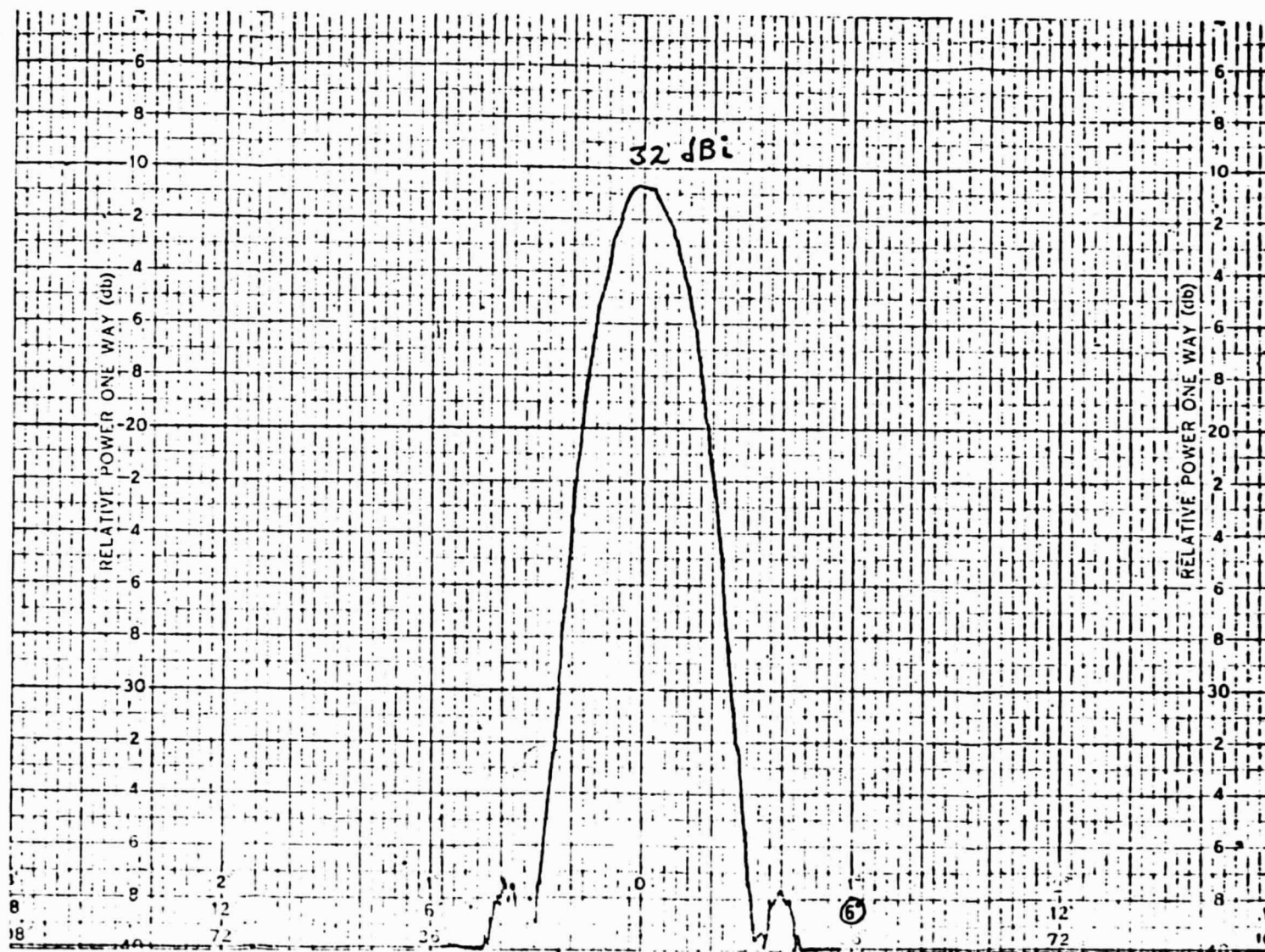


FIGURE 14 AZIMUTH ANTENNA PATTERN
(H PLANE)

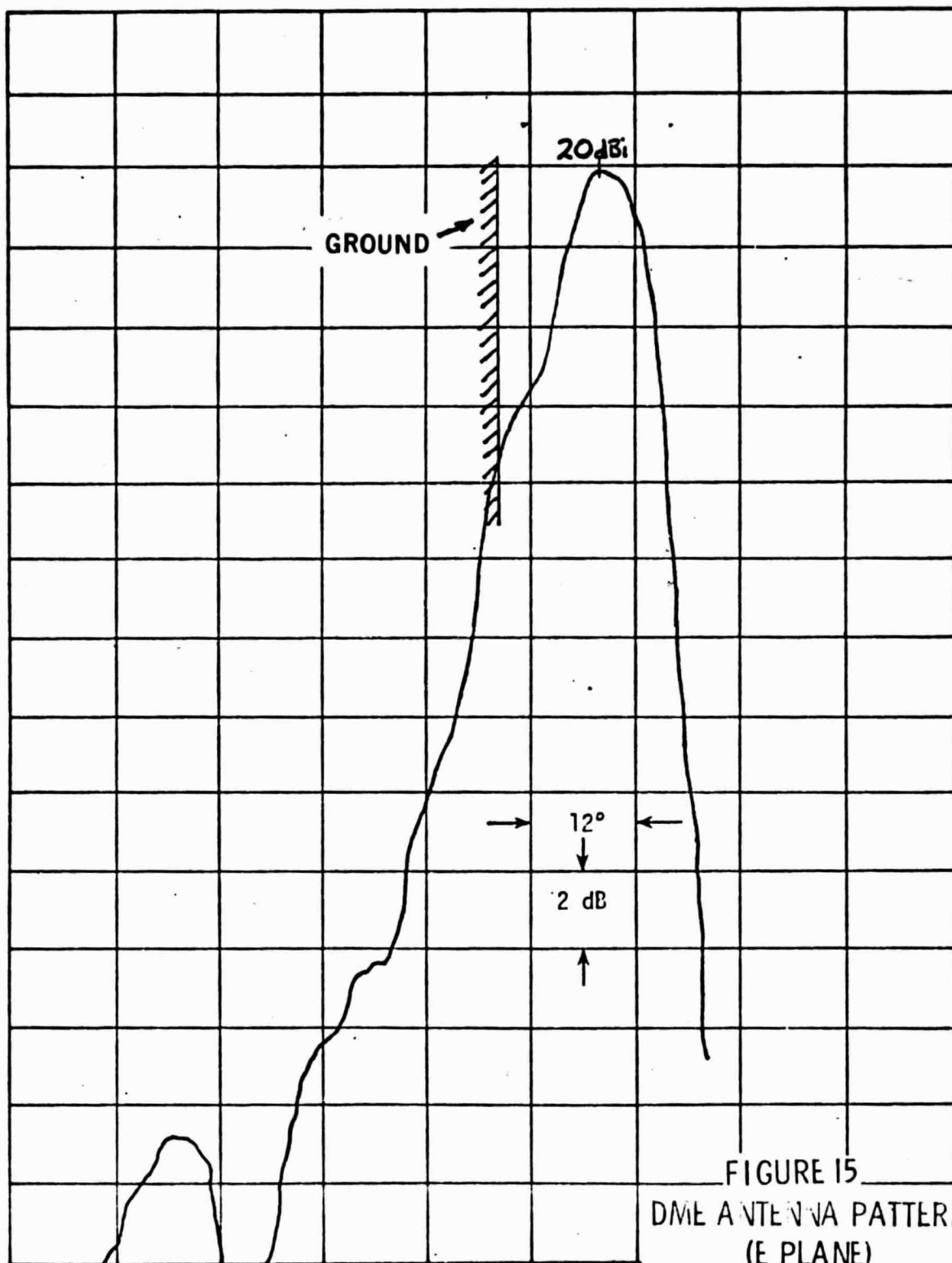


FIGURE 15
DME ANTENNA PATTERN
(E PLANE)

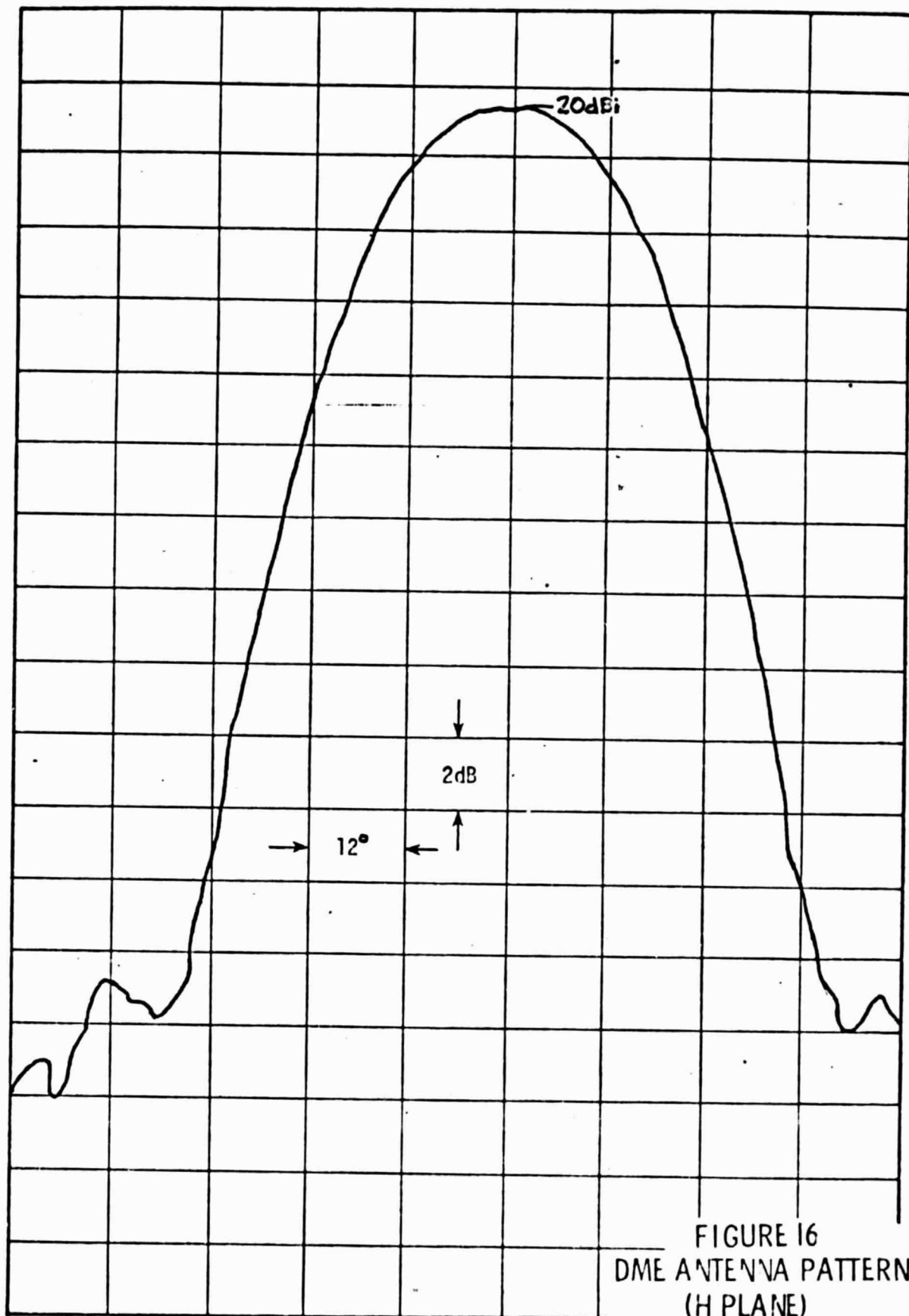


FIGURE 16
DME ANTENNA PATTERN
(H PLANE)

3.3 AGC Loop Description

The Orbiter MSBLS receiver builds up an analog AGC voltage level for each of the 3 functions: azimuth, elevation, and DME. These voltage levels are set by the previous scan and act as a memory for controlling gain in the IF amplifier. The following sequence of events will help explain this AGC memory function. The gain is maximum until 3 azimuth, or 3 elevation, or 3 DME pulse pairs are received, the IF amplifier is connected to the proper AGC memory voltage level to test the strength of the signal. If the strength is the same as on the previous scan, the video level of the pulses will be 3 volts and the data will be processed. The receiver is constantly trying to maintain a 3 volt video level. If the signal strength is greater than on the previous scan, the AGC loop will cause the IF amp to be less sensitive at about 1dB/scan. If this were the only effect, the decrease in gain of this 5 scan/sec system would be 5 dB in a 1 second period. However, the AGC is biased toward becoming more sensitive at a constant rate around 1dB/sec. Including this bias effect the AGC will decrease gain at about 4dB/sec (# of scans - 1) when a stronger signal is received. If the signal strength is less than on the previous scan the receiver increases gain at its natural bias rate of 1 dB/sec. If the expected signal changes by more than 3 dB in 200 milliseconds (1 scan period) the receiver drops lock and sets the validity bit to "1" (invalid). If the signal is too strong (after losing lock) the gain is decreased at 4 dB/sec. If it is too weak, the AGC slew rate increases to 3 dB/sec (Reference E).

In reality, the AGC tracking rates are a function of the signal strength as shown in Figure 17. The weaker the signal, the higher the positive tracking rate, but the negative tracking rate is smaller when the gain is high. It should be noted that the AGC was computer modeled with nominal component values assumed (Reference F).

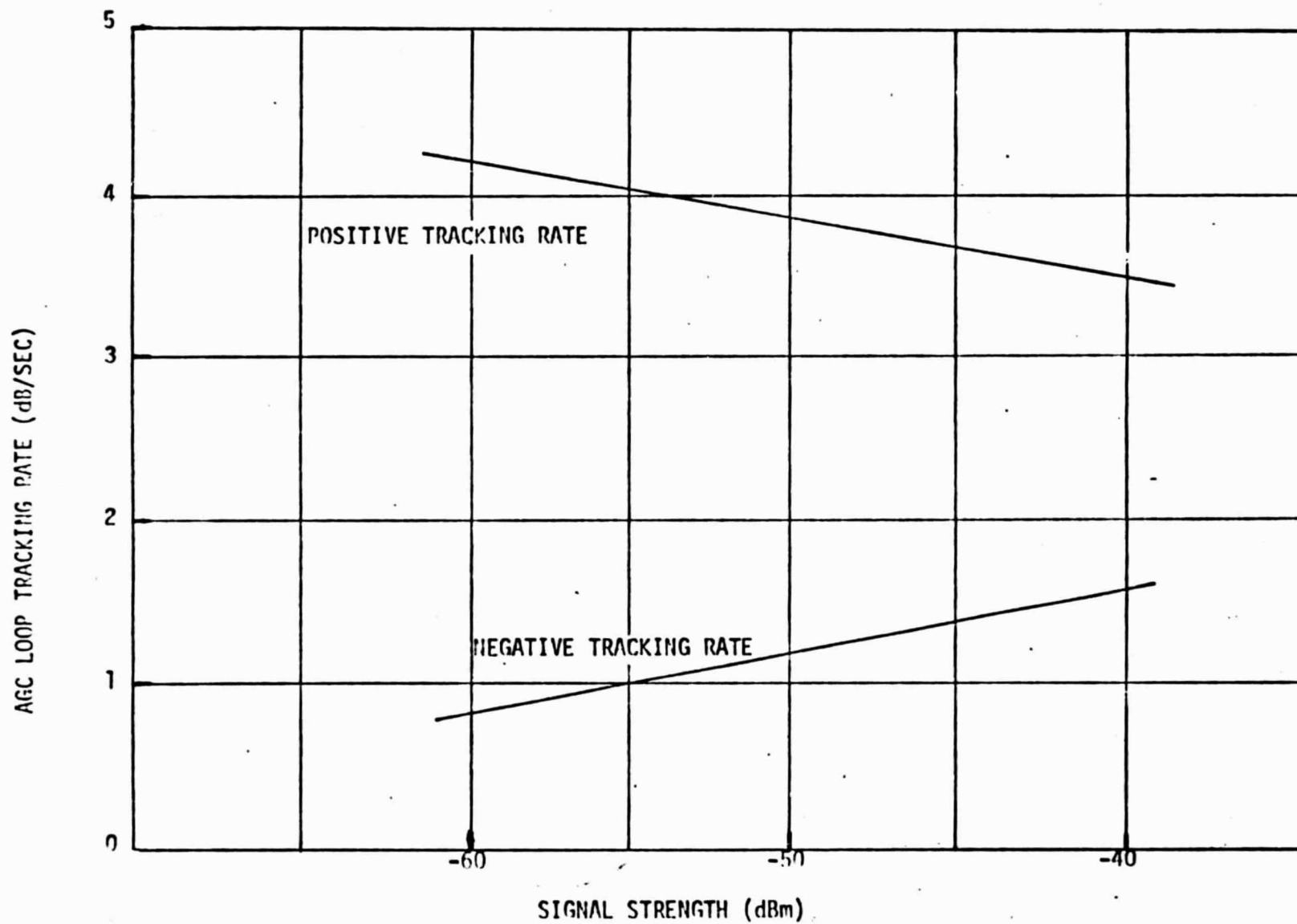


FIGURE 17 AGC LOOP TRACKING RATE vs SIGNAL STRENGTH

4.0 RESULTS

The total received powers as a function of time for the 3 wind cases appear in Figures 18 through 26. These signal levels were computed for each second from separation to touchdown.

The plots are ordered with the elevation signal power histories first, then the azimuth power histories, and finally the DME receiver power histories. The wind cases are ordered: no winds, cross winds with gusts, and headwinds with gusts.

At no instance during these ALT simulations was the receiver threshold exceeded. The worst SNR encountered during the simulation was 23.3 dB which was the DME received power at the start of the simulation runs. Signal strength was shown to be no source of concern.

However, the AGC loop capabilities were occasionally exceeded. The highest rate of change of signal strength from second to second calculated was +2.4 and -2.0 dB. Although these figures prove that on a second-to-second basis the signal level change does not exceed AGC tracking capabilities, reasons exist why closer scrutiny is necessary for a scan by scan analysis.

First, the receiving antenna RDP is given with only 1 dB resolution. This introduces a random error of .5 dB in the calculated power levels. In Figure 10, the depth of the interference pattern nulls is shown to have a maximum value of 2.2 dB between 1 and 2 degrees pitch down within a .5 degree change in look angle. Look angle pitch rates of over 2 degrees per second were experienced during all simulations regardless of wind. Angular rates of 12 degrees per second showed up under high wind conditions. When these rates occur over this region of bad interference it is apparent the scan-to-scan (.2 second) signal level may drop by 2.2 dB. Since this RDP is for the MSBLS antenna farthest from the Orbiter center line the look angles of the

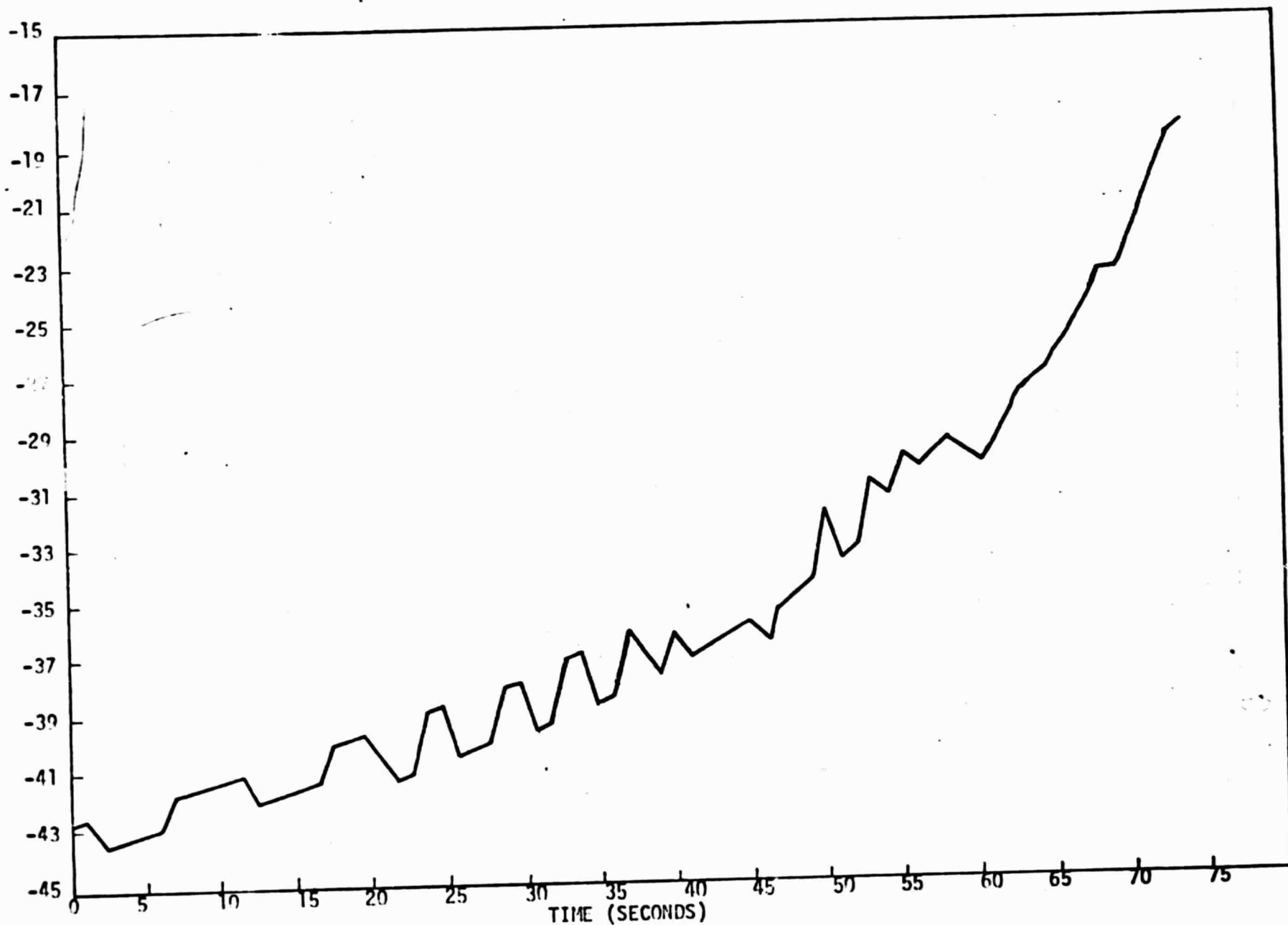


FIGURE 18 RECEIVED POWER HISTORY - ELEVATION SIGNAL - NO WINDS

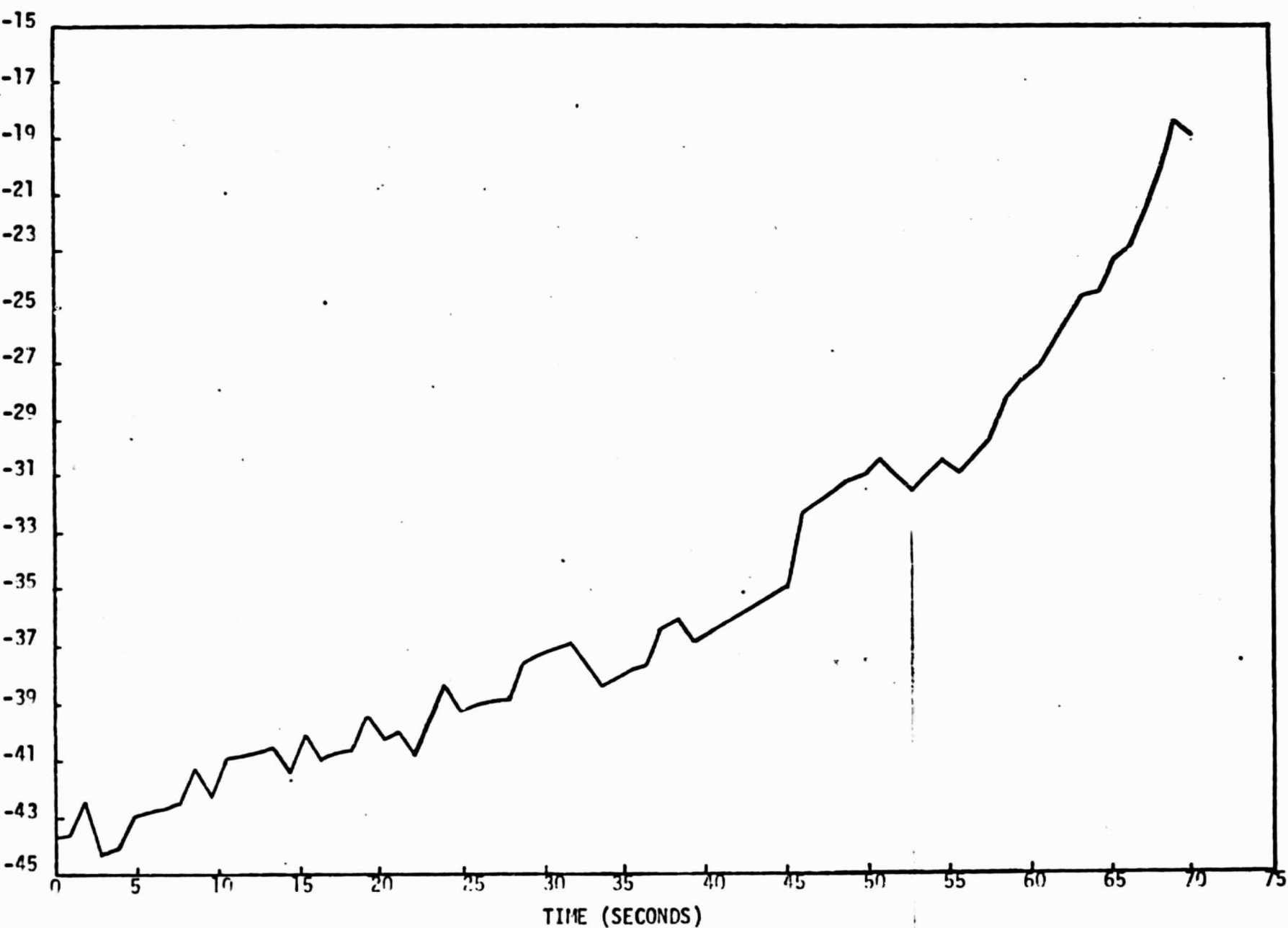


FIGURE 19 RECEIVED POWER HISTORY - ELEVATION SIGNAL - CROSSWINDS & GUSTS

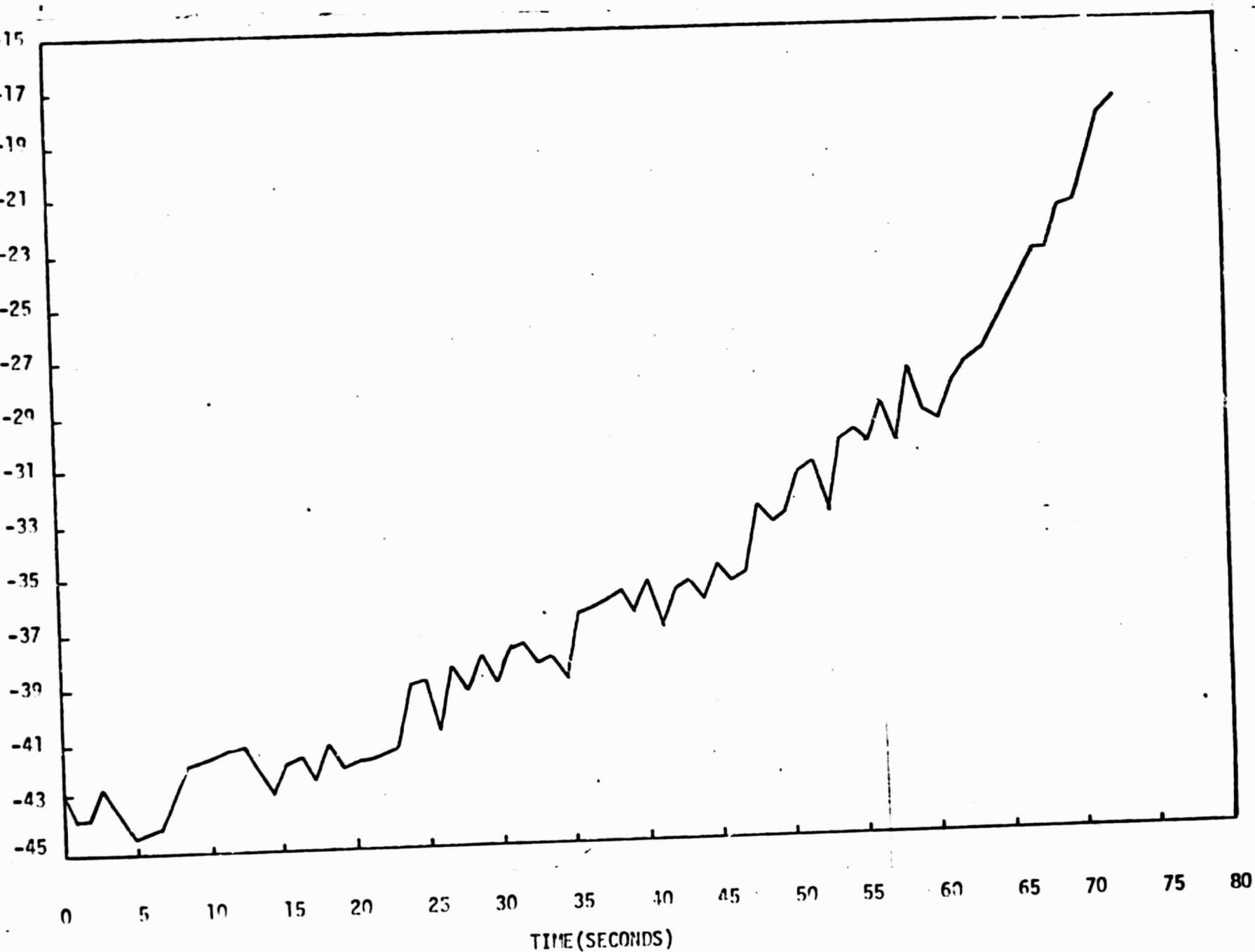


FIGURE 20 RECEIVED POWER HISTORY - ELEVATION SIGNAL - HEADWINDS & GUSTS

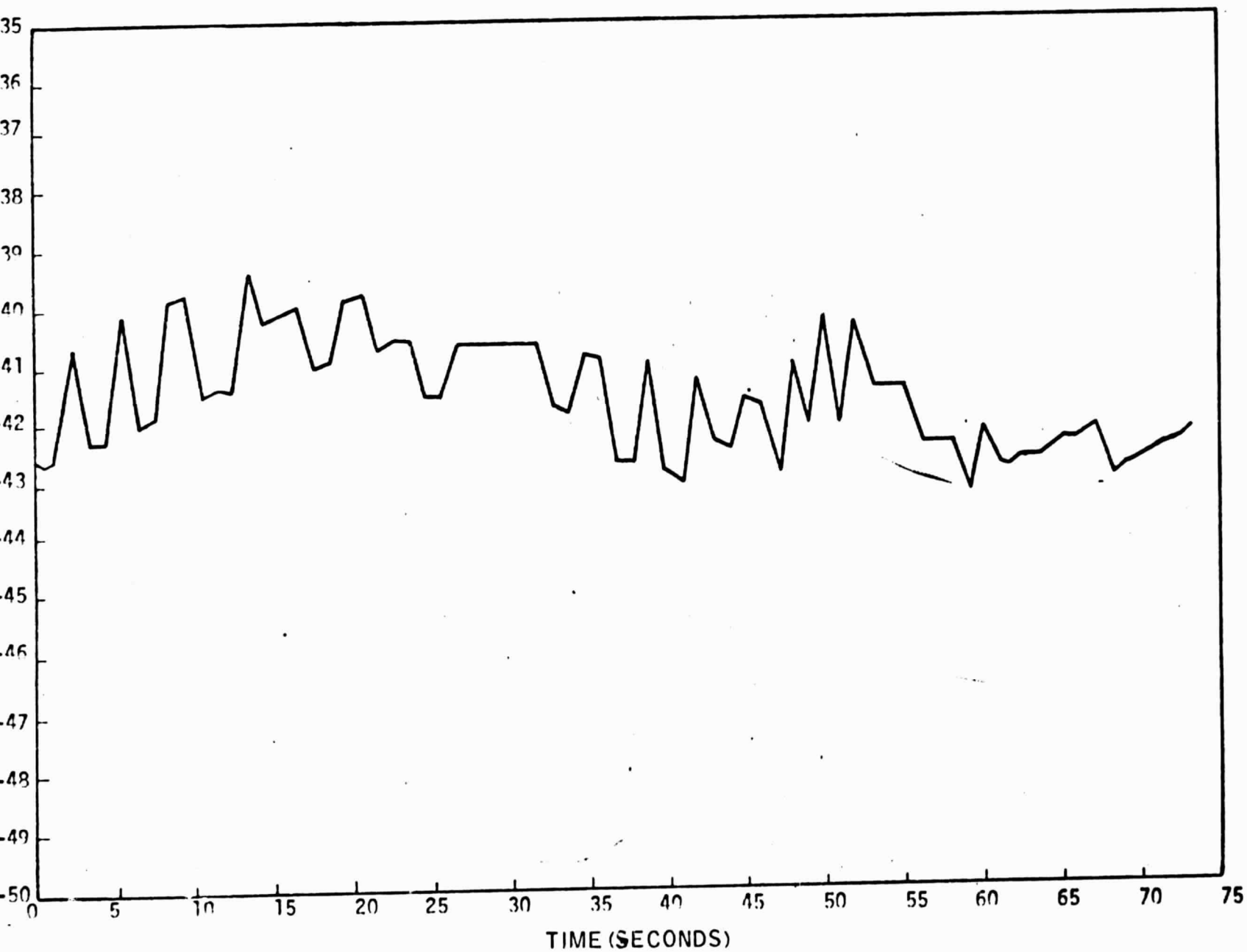


FIGURE 21 RECEIVED POWER HISTORY - AZIMUTH SIGNAL - NO WINDS

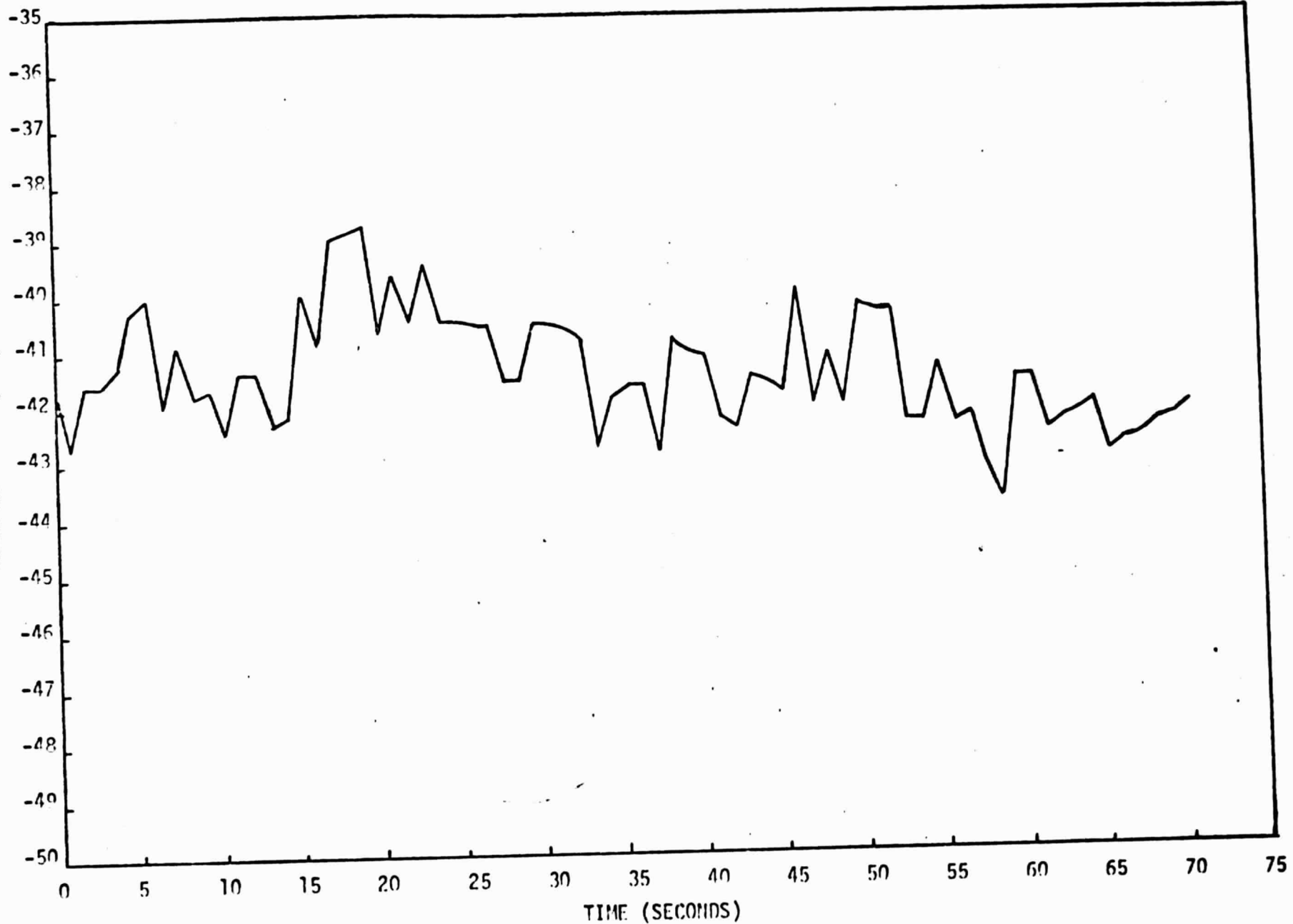


FIGURE 22 RECEIVED POWER HISTORY - AZIMUTH SIGNAL - CROSSWINDS & GUSTS

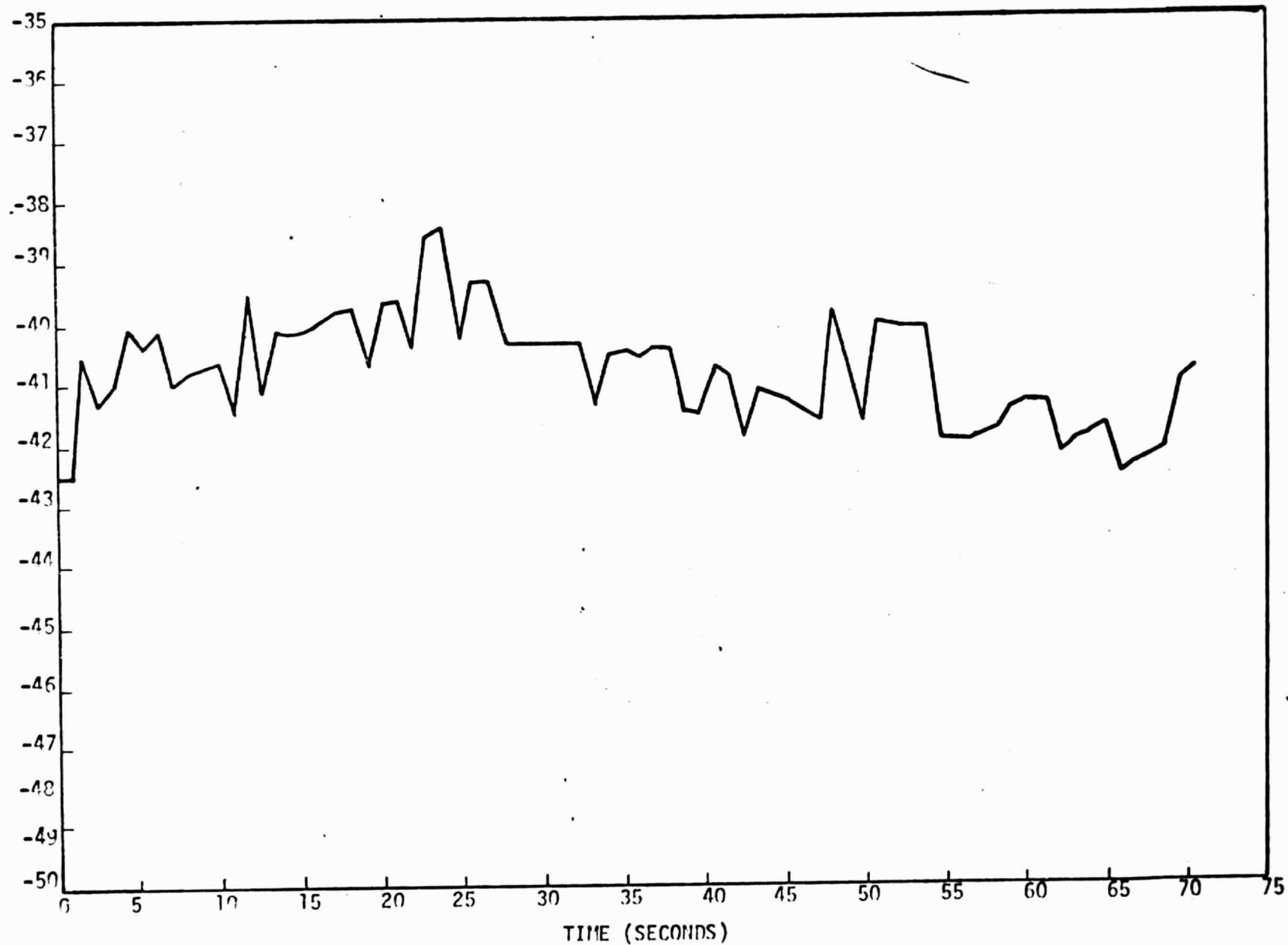


FIGURE 23 RECEIVED POWER HISTORY - AZIMUTH SIGNAL - HEADWINDS & GUSTS

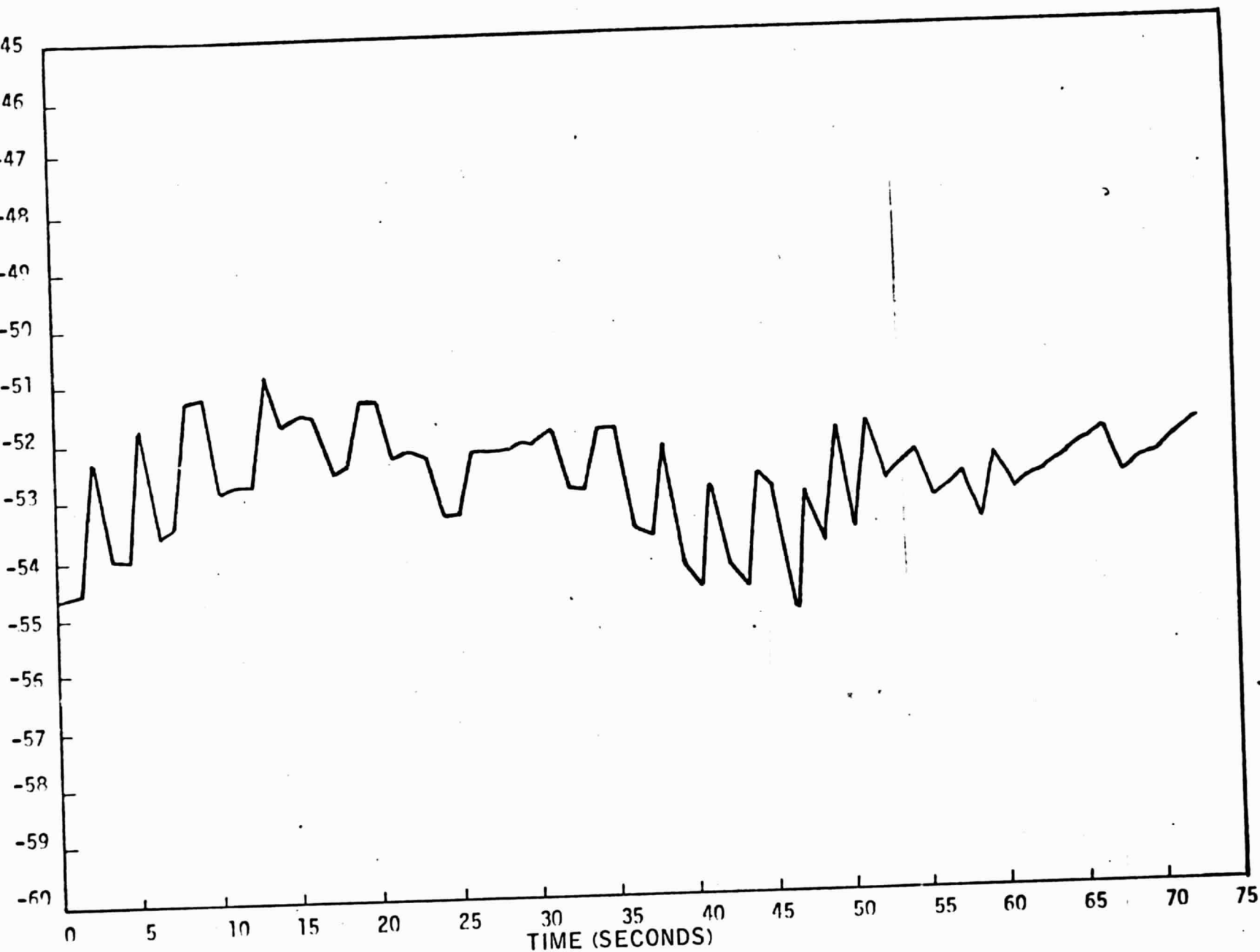


FIGURE 24 RECEIVED POWER HISTORY - DME SIGNAL - NO WINDS

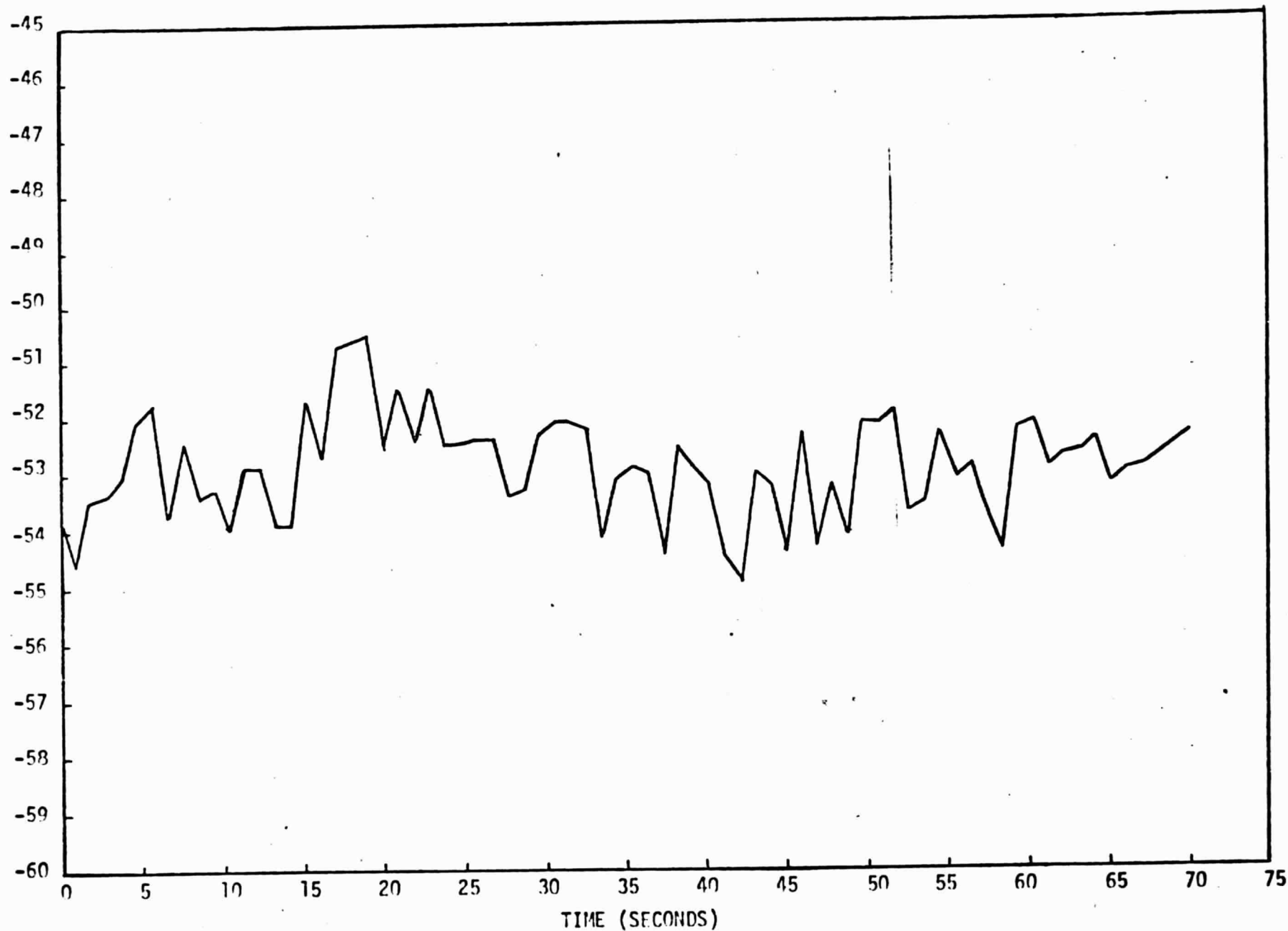


FIGURE 25 RECEIVED POWER HISTORY - DME SIGNAL - CROSSWINDS & GUSTS

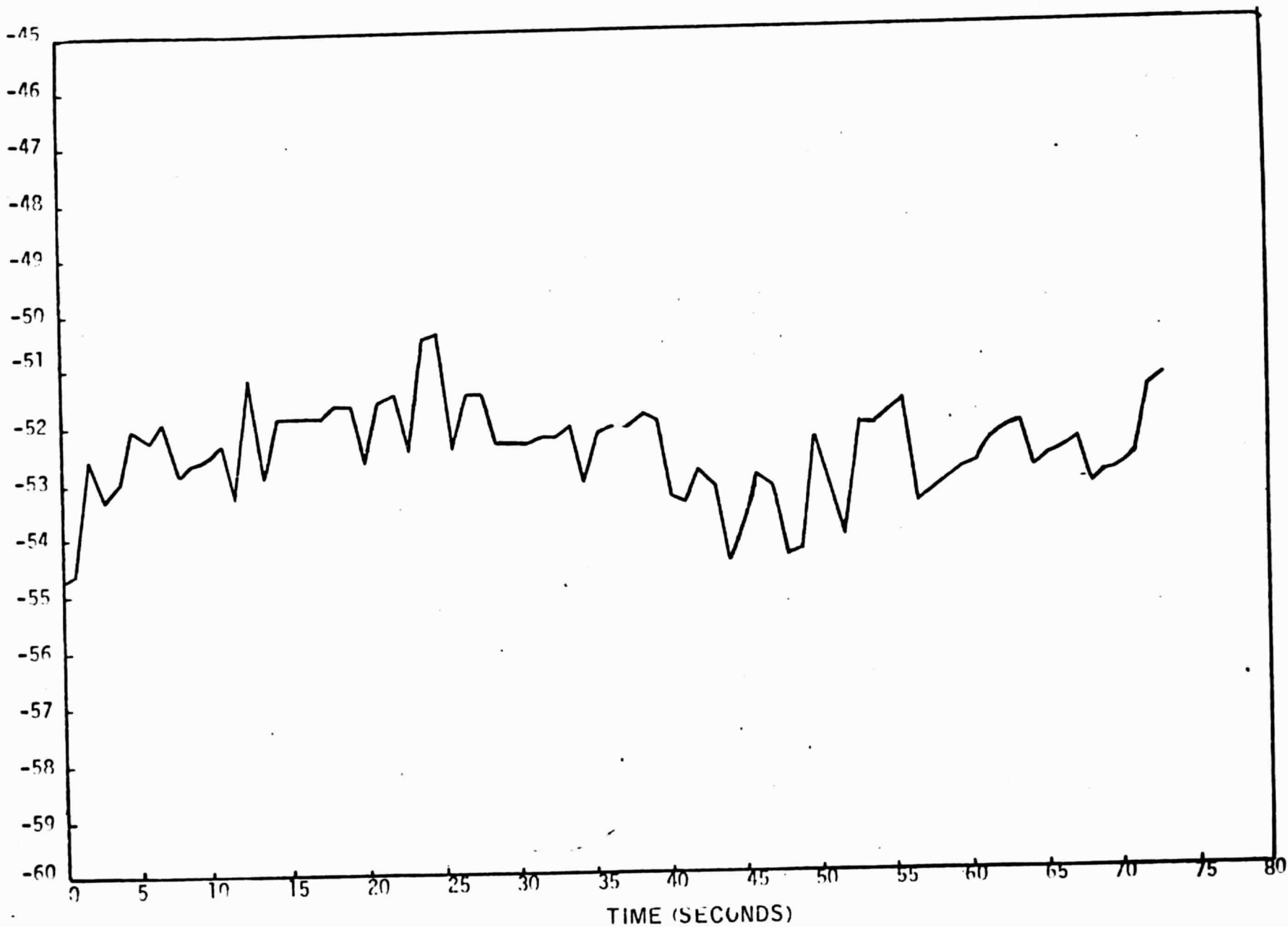


FIGURE 26 RECEIVED POWER HISTORY - DME SIGNAL - HEADWINDS & GUSTS

nulls may be shifted in the other RDPs.

Second, if the receiver power were slightly too strong on the first scan, the AGC may slew at over 4 dB per second (.8 dB/scan) to decrease gain by .8 dB. If the signal drops by 2.2 dB and the AGC loop decreases gain at the same time, the signal strength on the next scan will be over 3 dB lower than the AGC level which would result in loss of lock. The receiver must then identify 3 more pulse pairs, set the AGC level, test the next scan, then reset the data validity flag before processing of data may resume.

It is acknowledged that loss of data in the forementioned manner would seldom occur and would only momentarily inhibit the processing data. Also, due to the multiple antenna configuration of the MSBLS, it is not necessarily true that loss of lock would occur at the same time in all receivers. This depends on the null positions on the other unavailable RDP's.

5.0 CONCLUSIONS

The results of this study show that a 2.2 dB variation in the antenna pattern along with the .8 dB/scan change from the AGC may produce a loss of MSBLS data. If the simulated TPS for ALT further degrades the antenna performance more significant data drop outs may occur. The effects of simulated TPS and the nose boom along with AGC loop laboratory data should be analyzed to determine if more significant dropouts occur before recommendations are made for hardware or system changes. These could include altering the AGC rate, the simulated TPS or the antenna.

6.0 REFERENCES

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